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THE VALUE AND UTILITY OF INFLIGHT ONBOARD SIMULATION

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This report illustrates the application of a framework that could lend greater coherence to U.S. security planning. It ~~also~~ attempts to provide policymakers with a broad overview of the contribution the U.S. ~~United States~~ Air Force could make in protecting U.S. and Western interests in Southwest Asia. This study ~~concerns itself~~ is concerned with the ~~most~~ demanding military problem--the possiblity of a Soviet invasion of Iran aimed at securing control over the oil fields of the Persian Gulf. (3) ~~Section II~~ discusses American national objectives in Southwest Asia and the broad national strategy the U.S. government has formulated to achieve these objectives. Next, it ~~Section III~~ examines the nature of the Soviet threat and provides some background on strategic considerations that influenced the development of U.S. military strategy. The next sections ~~Section IV~~ discusses U.S. military strategy for possible contingenies, the forces being considered for operations in this theater, and the programs initiated to support this strategy. ~~Section V attempts~~ The last section tries to identify what specific military capabilities the USAF should enhance or develop to better support U.S. strategies and national objectives, ~~. Section VI lays~~ and lays out ~~in some detail~~ a concept of operations for one of these capabilities, strategic mobility for tactical aircraft.

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Onboard Simulation (OBS) provides computer-generated synthetic targets which are projected in the pilot's head-up display (HUD). The target changes size and perspective to account for relative position between the target and attacker. OBS was flight test demonstrated in the USAF Integrated Flight and Fire Control (IFFC) advanced development program. A review of IFFC experience with OBS is provided, including an estimate of direct cost savings attributed to OBS. A decision analysis is performed to assess the use of OBS for operational pilot training in aerial gunnery. Results indicate that a training mix of OBS synthetic target encounters balanced with real target encounters can improve the quality of training.

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FOREWORD

The work described in this report was performed by the author as a case study in partial fulfillment of a Master of Science Engineering Management degree at the University of Dayton. Selection of onboard simulation as a topic for study was motivated by the author's work experience as flight test director for the USAF Integrated Flight and Fire Control (IFFC) advanced development program. The author extends sincere appreciation to Mrs Marvelin Dotterer, Ms Shirley Milne, and Ms Colleen Goebel for typing support; Mr Gary Hellmann (AFWAL/FIGX), Lieutenant Brian Brady (AFWAL/FIGX) and Mr Charles Scolatti (McDonnell Aircraft Co.) for consultation.

This case study consists of seven chapters. Chapter 1 introduces the subject matter with a statement of the problem to be addressed and a brief preview of the approach to be applied in accomplishing this study. The reader should develop an understanding of how the United States Air Force (USAF) trains F-15 pilots to use the aircraft gun system for air-to-air combat and some of the limitations of current training methods. The concept of inflight Onboard Simulation (OBS) is introduced, and its potential for improved training is discussed. Decision theory is suggested as the mechanism for exploring alternative applications of OBS.

Chapter 2 provides a background of the subject matter with a more detailed description of OBS and decision theory. Original

development and demonstration of OBS is presented along with discussion of strengths and weaknesses. Future applications bring out the strong potential of the technology. Decision theory is discussed in the context of multiple attribute utility analysis used in this case study rather than a broader discussion of all possible decision methods. Appropriate examples are referenced.

The value of OBS is developed in Chapter 3 by studying experience gained in actual use. An estimate of dollars saved during the Integrated Flight and Fire Control program is computed. Baseline performance statistics are derived for use in later chapters.

A basic structure for the decision analysis is presented in Chapter 4. This includes definition of objectives for applying OBS to pilot training and developing a list of reasonable alternatives. Effectiveness measures, called attributes, are assigned which provide the means for quantification of objectives.

Chapter 5 deals with the core concept of utility analysis decision theory. That is, a decision maker's attitude toward the value of possible outcomes. This might also be called preferences for the outcomes. Utility functions are developed for each of the attributes assigned in the previous chapter. A matrix of specific utility values is developed by assigning a value to all attributes for each alternative.

Chapter 6 presents the execution of the multivariate utility analysis. Expected utility is calculated for each alternative using the general form of the utility function. A cross-section of indivi-

dual decision makers is used to assign scaling factors indicative of each individual's attitude of the relative importance of the different attributes. The expected utilities are recomputed for each decision maker.

Results and conclusions are presented in Chapter 7. Recommendations are based on the fact that the most desirable alternative exhibits the highest expected utility.

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LIST OF TERMS

AAG - Air-to-Air Gunnery

ACE - Air Combat Evaluator

ACM - Air Combat Maneuvering

ACMI - Air Combat Maneuvering Instrumentation

AFB - Air Force Base

AGG - Air-to-Ground Gunnery

BATR - Bullets-at-Target-Range

BMG - Bombing

ET - Embedded Training

HMD - Helmet Mounted Display

HUD - Head-Up Display

IFFC - Integrated Flight/Fire Control

LCOS - Lead Computing Optical Sight

OBS - Onboard Simulation

USAF - United States Air Force

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Inflight Onboard Simulation (OBS) is a concept which allows the pilot of a tactical fighter aircraft to fly realistic weapon delivery encounters against a computer generated synthetic target. This target is generated onboard the aircraft by a dynamic target model and is presented visually to the pilot on his head-up display (HUD). The OBS concept was developed and demonstrated during the recently completed United States Air Force Integrated Flight and Fire Control (IFFC) advanced development test program. OBS was used extensively during the IFFC program and holds significant potential for application to operational aircraft as a pilot training device. The devised objectives of this study are to explore the attributes of OBS and, through decision analysis, develop a strategy for the USAF to determine how OBS might be applied to operational aircraft for effective pilot training.

For a long time, the aircraft gun was the primary weapon for aerial combat. During recent years, missiles have replaced the gun as the primary weapon, but the gun remains an effective and complementary weapon. "It is a close-in all-aspect weapon", and due to minimum range restrictions for employing missiles, "inside 3,000 feet, against a maneuvering target at most aspects, the gun is your only weapon" (4:9). However, effective use of the gun is highly dependent upon the amount and quality of training which a pilot receives.

Current gun training consists of basically two types; 1) live-fire attacks against aerial tow targets and 2) non-firing dynamic encounters against manned target aircraft. Each type of training has advantages and disadvantages which affect the quality of training in representing actual combat conditions.

Live-fire training encounters allow pilots the opportunity to actually fire the aircraft gun. Inexpensive plywood targets called Darts are deployed on a 4,000 foot cable behind an F-4 aircraft and the attacking aircraft shoots at the Dart. It is certainly desirable for a pilot to experience the sensation of firing bullets and become familiar with the switchology and procedures for firing the gun. Additional advantages are that the gun mechanism is checked out by periodic firing, and boresight of the gun can be confirmed if the target is hit. Major disadvantages are created because the engagement dynamics must be rigidly controlled to prevent any chance of bullets accidentally hitting the manned tow aircraft. Target aspect angle is usually limited to conditions shown in Figure 1-1 (20), and the target is airspeed limited. The net result is that live fire encounters against tow targets do not present the dynamics of an evasive target aircraft that wants to avoid being killed. Another disadvantage is the lack of an effective scoring system to know where the bullets are going. If bullets go through the Dart, then bullet position is known. If the bullets miss, it is difficult to determine whether the pilot did not track the target properly, or if the gun is out of boresight (misaligned), or combinations of both.

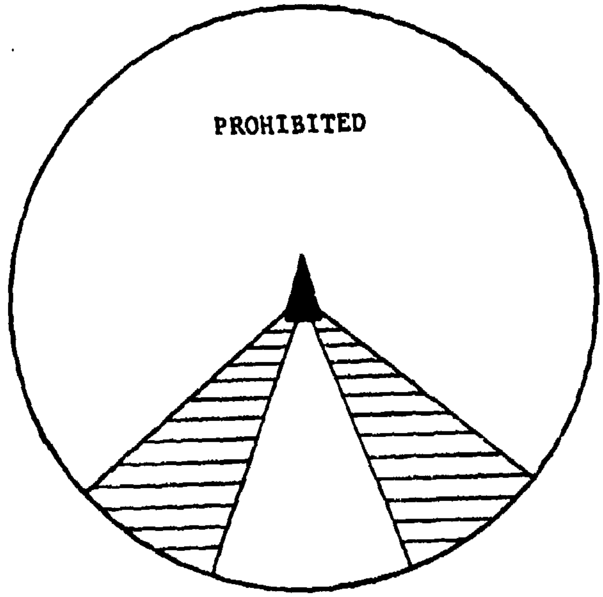


FIGURE 1-1
LIVE-FIRE TRAINING ENVELOPE

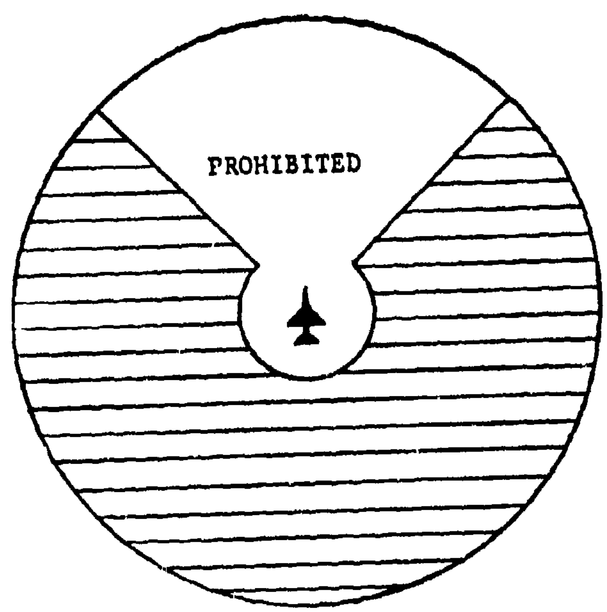


FIGURE 1-2
TACTICAL TRAINING ENVELOPE

The majority of gun training is performed in a tactical mode where a maneuvering manned aircraft is used as a target. No bullets are fired for obvious reasons, but very realistic dynamic encounters are created when the target aircraft maneuvers while attempting to escape. Gun camera film records the HUD scene when the attacking pilot pulls the trigger. Post-flight inspection of the film is used to determine if the target should have been hit. There are some major disadvantages to this type of training. Due to risk of mid-air collision, front quarter or head-on encounters are prohibited (4). Additionally, the aircraft must never come within 1,000 feet of each other. Figure 1-2 depicts the allowable zones for training.

Criteria for scoring kills from gun camera film is based upon consecutive frames where the gunsight pipper is superimposed on the target aircraft (4). This assumption is valid for rear quarter shots, but when target aspect angle is greater than approximately 40 degrees, lead angle must be inserted in order to hit the target (4). There is currently no convenient way to estimate proper lead angle from gun film. Onboard scoring would eliminate this scoring problem because it would provide an accurate model to determine hits.

OBS could be very useful toward reducing or eliminating some of the shortfalls in current training methods. The synthetic airborne target can be used for training in the front quarter where encounters are head-on. This can be done safely without risk of collision. Benefit would be very high because of the significant number of combat encounters which would be expected in the front quarter (19).

Onboard scoring would give pilots real-time feedback, telling them the position of the bullet stream and an estimate of the number of hits scored. When pilots know where they missed, they can compensate on the next shot. This learning process is much more productive than looking at gun camera film well after the mission and attempting to remember what happened. If a gun is improperly boresighted, onboard scoring can help to determine such. Whenever scoring shows hits on the target, but no hits were experienced, one should suspect a gun alignment problem.

For tactical training, scoring would eliminate sole dependence upon pipper on target as scoring criteria. As aspect angle increases beyond 40 degrees, lead angle is required to hit the target which makes the pipper on target criteria incorrect. The pilot can quickly learn by trial and error what amount of lead angle is needed in given situations to score hits on target.

OBS is not without drawbacks, however. As previously mentioned, currently available versions of OBS are symbology limited to the HUD field-of-view. Encounters can be structured to keep the target within the HUD and demonstrate all aspect encounters. This teaches pilots proper lead angles to achieve bullets on target, but is weak in teaching air combat maneuvering tactics. That is, an ability to maneuver relative to an adversary aircraft and close in for a shot while guarding against a maneuver by the adversary which places him in a position of advantage. A helmet mounted display which allows all-aspect presentation of the synthetic target would eliminate much of this problem, but such a capability has not been demonstrated.

Pilots who have flown OBS think it has good training potential, but not at total sacrifice of "real" (tactical or live-fire) training. Also, the cost of installing OBS on operational aircraft must be considered. An OBS purchase would reduce the amount of available training funds. Cost savings must more than account for the capital investment to make a purchase worthwhile.

It is obvious that a more detailed analysis of relevant parameters is needed before a decision can be made about applying OBS to operational air-to-air gunnery training. A systematic method is needed to weight the advantages and disadvantages of OBS. Decision theory will be applied to the problem.

1.2 Approach

Research began with a thorough literature search of onboard simulation concepts and applications. References describing decision theory methods were used to determine the type of analysis to be applied.

OBS is introduced to the reader with a detailed description of this new concept. A survey of the IFFC program was performed to develop an estimate of cost savings attributed to OBS and to identify useful applications. Data was based on information provided by the contractor program manager and from a detailed review of individual flight test reports. Flight test cost and performance data formed a needed baseline for further analysis.

The main issue examined in this study concerned a possible decision by the Air Force to invest in OBS for retrofit to operational fighter aircraft as a pilot training device. Many issues were

taken into account before a specific course of action was recommended. To begin, objectives of the decision process were developed and pertinent attributes selected for the objectives. Analysis considered purchase cost, operating cost, effectiveness of training, pilot preference, and other appropriate factors. A model of current Air Force training will be developed from available information and was serve as the standard of comparison from which alternative options were assessed.

Alternatives considered began with keeping training as it currently exists, progressed to increasing involvement of OBS, and concluded with an option for converting all training to OBS. Expected utility was calculated for all alternatives and used as the final selection criteria. A sensitivity analysis was performed to establish further confidence in the results. Final conclusions determine if OBS deserves consideration for major Air Force application.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Onboard Simulation

Piloted flight simulators generally consist of some form of ground based device which attempts to realistically represent the conditions of flight. The level of sophistication may vary from a simple desk-top unit to a life-size cockpit replica complete with motion cues and live-like visual scenes. The fidelity or realism of flight simulation has matured to the point that a significant portion of commercial airline pilot training is performed in simulation. However, accurate representation of highly dynamic aerial combat scenarios remains a challenge even to the most sophisticated state-of-the-art simulators. Onboard simulation offers a new approach in combat simulation by flying the pilot in a real aircraft and simulating only the external conditions such as target aircraft. By using actual flight conditions and dynamics, much of the simulation burden is eliminated. More detailed discussions of OBS are presented later in this chapter.

2.1.1 Background

The concept of inflight onboard simulation (OBS) was first demonstrated during the United States Air Force Integrated Flight and Fire Control advanced development program. Flight testing of the IFFC system occurred between July 1981 and January 1983. Primary objectives of the program were to demonstrate the feasibility of integrating the flight and fire control systems of a fighter

aircraft to achieve improved weapon delivery performance in air-to-air gunnery (AAG), air-to-ground gunnery (AGG) and bombing (BMG). Integration consisted of using fire control error signals as inputs to the flight control system which, when coupled, would control the aircraft to null the errors and keep the weapon line bearing upon the target. Landy (12) and Sims (17) provide excellent overviews of the IFFC program.

OBS was originally conceived as an alternative to developing a dedicated IFFC hot bench unit. A hot bench is a test stand which can be parked on the ground next to the aircraft and is used to generate test signals for checkout of aircraft susbystems. A unique, and thus expensive, hot bench would have been designed and developed to meet specific ground test requirements of the IFFC system. OBS appeared to be more attractive than a hot bench for several reasons. OBS was expected to perform complete closed loop system test functions with the added advantage of being self-contained to the aircraft. A small junction box was needed to simulate sensor inputs but otherwise, OBS consisted entirely of software in one of the aircraft digital computers. Cost of an OBS system was expected to be much less than a dedicated hot bench. An even greater advantage of OBS was that it would not be restricted to ground use, but would be operable in up and away flight. This advantage was significant, but the full potential of inflight OBS was not realized until flight testing was begun.

Once IFFC flight test was underway, experience with OBS grew and software modifications were made to expand its capability. Engineers

quickly learned to use OBS as a hardware-in-the-loop test facility for complete closed loop weapon delivery tests during pre-flight checkouts. IFFC software changes could be tested on the aircraft prior to flight. Pilots were able to become familiar with total system operation using OBS on the ground and in the air. OBS was a valuable tool for IFFC system development because weapon delivery encounters could be performed rapidly and could be duplicated. Much more data could be collected per flight than was possible using actual targets with as many as 83 OBS encounters recorded in one flight (10).

After 24 IFFC development flights had been completed, the electro-optical target sensor was damaged. Without this sensor, tactical encounters with real targets could not be performed, since there was no way for the IFFC aircraft to know target position. OBS suddenly became the only means of testing until the sensor could be repaired. In the interim, eighteen development flights were successfully completed. After tactical testing resumed, an AAG flight was performed using an F-106 target aircraft. During this flight the IFFC pilot commented, "This is just like flying against the OBS target" (14). Such a comment endorses the realism of OBS and lends credibility to the idea of applying OBS to operational pilot training.

2.1.2 Description

Onboard Simulation provides simulated targets for both the air-to-air and air-to-ground modes. In the air-to-air gunnery mode, a delta wing aircraft is projected in the head-up display HUD. This target changes size and orientation in accordance with the relative

geometry between the target and attacker as perceived from the attacker viewpoint. Target maneuvers can be varied from simple straight and level flight to very dynamic evasive maneuvers. The level of difficulty can be controlled for the appropriate skill of the pilot. Many different encounters can be stored in computer memory and randomly presented (if desired) so the pilot cannot anticipate the type of maneuver to be performed. When the attacking pilot is in position to fire at the target, onboard scoring is used to statistically score the expected number of hits on target. The bullet scoring model is contained in the Air Combat Evaluator (ACE) software. A Bullets-at-Target-Range (BATR) symbol, sometimes called a hot point, is displayed to the pilot so he gets immediate feedback on where his bullet stream went relative to the target. Hits will be scored if the BATR is superimposed on the target. Scoring is activated whenever the trigger is depressed, and can also be used in simulated firings at real aircraft targets. Figure 2-1 (10) is an example of IFFC HUD symbology including the synthetic target and scoring features.

In the air-to-ground modes, a target symbol is assigned a fixed three dimensional point in space and is displayed accordingly in the HUD. Absolute target position does not change, but the symbol moves in the HUD to account for aircraft motion. BATR and ACE scoring are used for air-to-ground gunnery attacks to score predicted bullet hits, whereas estimated miss distance is computed for bombing attacks. Altitude of the synthathic ground target can be set at any desired altitude so that the weapon delivery encounters can be performed at safe altitudes without the risk of flying into the

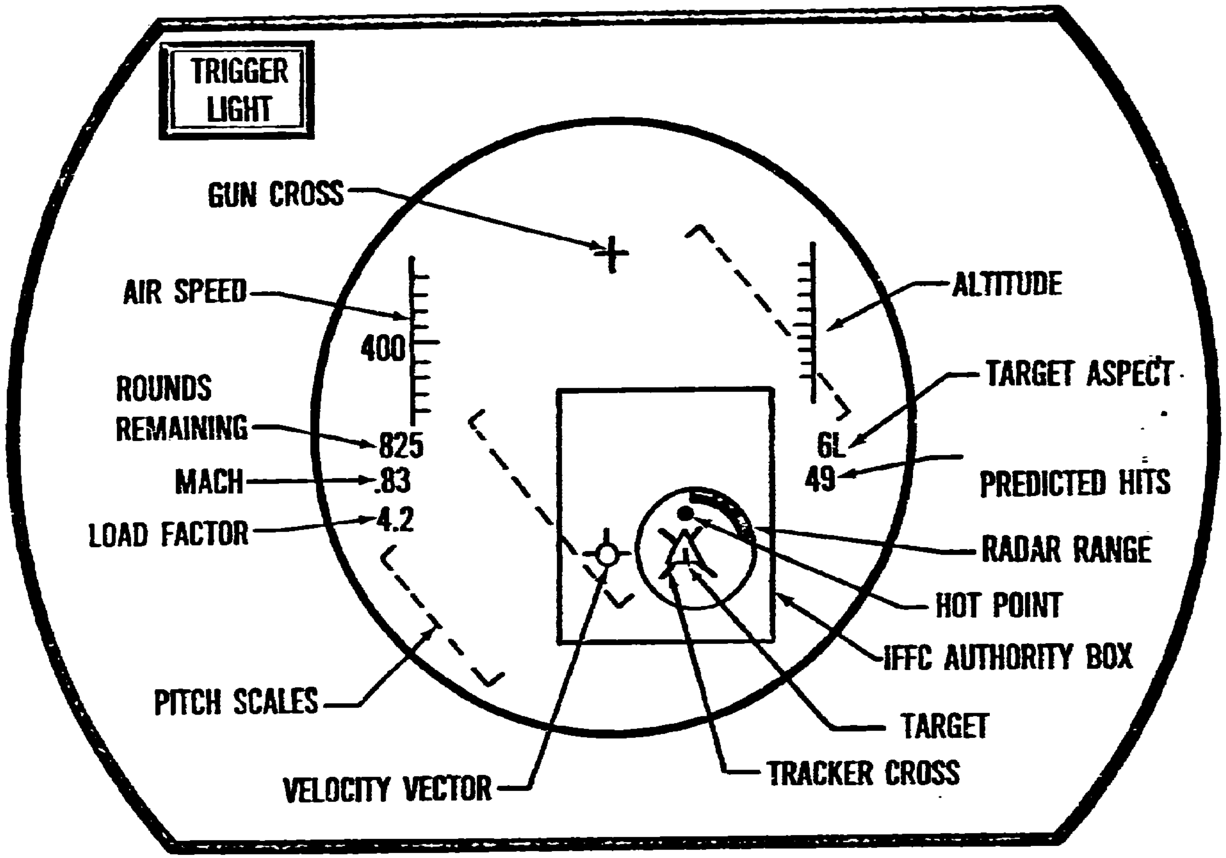


FIGURE 2-1

IFFC HUD SYMBOLOGY

ground. Several different encounters can be stored in computer memory.

OBS possesses many advantages for airborne pilot training and testing of aircraft weapon systems. It significantly reduces the requirement for expensive real targets needed during checkout, validation, and evaluation of a system. Inflight OBS is very realistic because only the target and target sensors are being simulated. The attacking aircraft uses all onboard subsystems, such as fire control, flight control, motion sensors, etc., in the same manner as in attacking real targets. The pilot actually flies the aircraft and experiences all of the motion sensations of the real flight environment. Many potential flight hazards are eliminated with the synthetic target. Head-on air-to-air gunnery encounters can be performed with no risk of mid-air collision. Onboard scoring eliminates the requirement to use live weapons with the associated safety problems. Many more encounters can be performed per flight hour with OBS, because after each weapon encounter is completed, a simple initial condition reset is all that is needed to prepare for another encounter. When using real targets, lengthy set-up time is required to properly position the target and attacker, resulting in fewer encounters per flight. During the IFFC program, OBS demonstrated all of these advantages. The next chapter will develop an estimate of cost savings attributed to OBS.

2.1.3 Potential Future Applications

The IFFC mechanization of OBS may have only scratched the surface of a much larger potential. It would be possible to increase

the benefits attainable with OBS by extending the capability to simulate total mission requirements. Air-to-Air OBS is currently limited to short range gun encounters where the target remains within visual range. An interface with long range radar displays could be used to display a synthetic target at maximum sensor detection range. Then, as the encounter progresses, the attacker could simulate long range missile attack, within visual range missile attack, and finally, short range gun attack. This total mission capability would have even greater benefit as a training device.

OBS target presentation could be improved in several ways. An interactive target model has been developed for ground based simulators which allows the target to be reactive to the attacker maneuvers. Applying this type of model to OBS would allow the synthetic target to behave very realistically like an enemy who is trying to avoid being killed. A helmet mounted display would enable the target to be displayed at any appropriate aspect angle, eliminating the HUD field-of-view restriction of the current OBS. Several targets might be displayed simultaneously to represent the multiple target aerial engagement which is difficult and expensive to represent in training with real target aircraft, but would be expected in actual combat conditions. Heintzman (6) refers to this advanced form of OBS as "Embedded Training (ET)". Difficulty in accurately simulating the tactical fighter environment in ground based simulators makes ET an attractive training method. It can provide a very realistic environment where it is safe to fire simulated weapons against a synthetic target.

Enhanced OBS or ET can be related to the Air Combat Maneuvering Instrumentation (ACMI) training aid which is used by the Air Force for air-to-air missile training. Two or more aircraft engage in mock aerial engagements while onboard instrumentation telemeters aircraft state data to ground receivers. Ground systems display the encounter in real time to training officers who monitor the encounter. Viewing options allow the encounter to be displayed from any vantage point. All information is recorded for pilot debriefing after the mission. "This is really the biggest advantage to a student pilot. His aerial engagement is reconstructed in complete detail...so he can analyze his performance and pick out mistakes 45 minutes to an hour later" (1:77). Enhanced OBS is even better than ACMI because it provides the pilot with feedback during the encounter so he can assess his performance in real time. In addition, he can quickly repeat the very same encounter simply by resetting to the initial condition. Repeating the encounter allows the pilot to apply experience gained from the previous attempt and he does not have to wait until after the flight. All encounters can be recorded onboard the aircraft for post-flight review and compatability with ACMI real-time ground displays would be maintained.

It appears that OBS has significant growth potential to become a full mission training aid for tactical fighter pilots. A high level of realistic training can be provided safely at lower cost than currently possible using real aircraft targets. The OBS capability as demonstrated in the IFFC program, is a significant step toward achieving the full potential of this new technology.

2.2 Decision Analysis Literature

"Decision analysis has emerged from theory to practice to form a discipline for balancing the many factors that bear upon a decision" (8:211). The basic purpose of using decision analysis is to develop an appropriate course of action from a set of defined alternatives which will provide the best possible outcome. Utility theory is a specific form of decision analysis which "indicates that the best possible alternative to take is the one yielding the highest possible expected utility" (16:80). The utility or value of all possible outcomes is established by identifying all of the attributes, or evaluation criteria, which are significant to the decision. Weights or scaling factors are assigned (see chapter 6) for each attribute to determine the relative level of importance between attibutes. The expected utility of a particular alternative is the weighted average of all attributes for that specific alternative.

Utility of any given attribute represents a decision maker's preference for one attibute value versus another. Various procedures (8,9,15,18) exist for evaluating utility functions because, "assessment of utility functions is as much an art as it is a science and, therefore, no single set of rules can be laid down that invariably result in a utility function" (9:188). A typical utility function ranges in value from a preference limit of 1.0 at the most desirable attribute level, and 0.0 at the least desirable level. Characteristics of the continuous function between these endpoints indicate a decision maker's attitude toward risk. A linear relationship represents a risk neutral attitude where the decision maker is indifferent

between accepting the expected value or the consequence of a fair 50-50 lottery. Indifference is defined such that "if a decision maker is indifferent between two alternatives, the expected utility of the alternatives is the same" (18:125). Risk proneness exists if the decision maker is willing to pay a premium to engage in the lottery or, in other words, if he prefers the lottery to the expected value. If a decision maker requires a "risk discount" (15:271), he is considered risk averse and prefers the expected value to the potential consequences of a lottery. Typical utility curves are presented in figure 2-2.

A major advantage of utility analysis is the ability to analyze a situation where the outcome is affected by multiple attributes, each of which might be measured in different units. Attributes can be described in terms of cost, time, safety, effectiveness, public opinion, and so on. Assignment of an independent utility function for each attribute provides a basis for converting all the attributes into a common frame of reference. This provides the analyst with a great deal of flexibility in considering a broad range of different attributes which may affect a decision outcome.

To begin a decision analysis, the analyst must be able to identify the problem and establish meaningful boundaries. A problem which is too vague or too broad will not converge to a best decision alternative. A set of clearly stated objectives must be developed with descriptors which point the direction for the analysis, such as to maximize safety or minimize cost. Caution must be exercised to capture all significant aspects of the problem without using unneces-

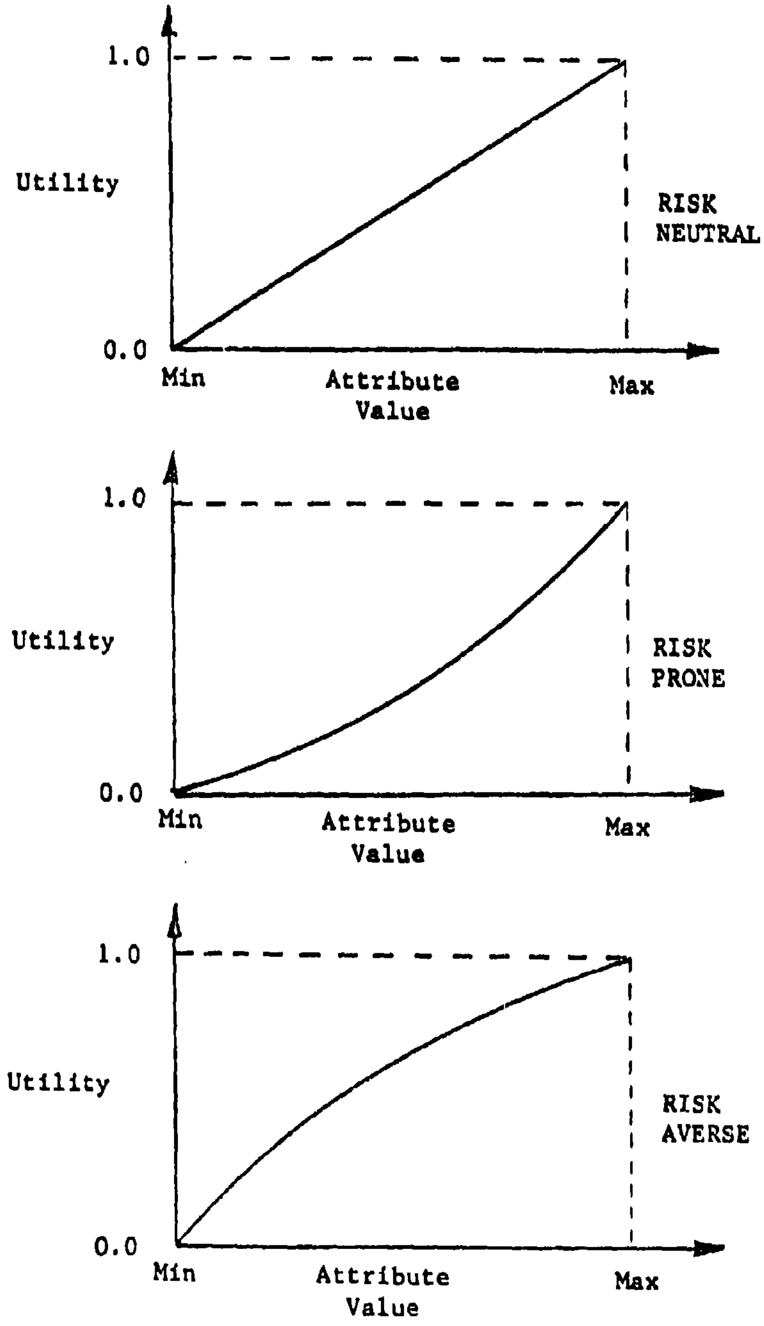


FIGURE 2-2

TYPICAL UTILITY CURVES

sary or weak objectives which quickly complicate the analysis. For each objective, an attribute is established as a measure of how well the objective is realized. Keeney and Raiffa (9:50) describe desirable properties of the attribute set as follows:

> "It is important in any decision problem that the set of attributes be complete, so that it covers all the important aspects of the problem; operational, so that it can be meaningfully used in the analysis; decomposable, so that aspects of the evaluation process can be simplified by breaking it down into parts; nonredundant, so that double counting of impacts can be avoided; and minimal, so that the problem dimension is kept as small as possible."

The most significant step in the decision analysis is to develop the multiple attribute utility function which defines the weighted average of the individual attributes. Without any simplifying assumptions, this function becomes unmanageably complex in order to account for every possible interaction between the number (n) of attributes involved. An assumption of independence among the attributes allows the collective assessment of n individual attribute utility functions rather than a complex n-attribute function. Two conditions must hold to maintain attribute independence: 1) Given any pair of attributes from the total set of n attributes, the decision maker's preference between the pair must not be affected by the value of the other n-2 attributes and, 2) the utility function associated with any individual attribute is not dependent upon values of the other n-1 attributes. Experience has shown that when systematically coping with four or more attributes, the independence requirement is robust enough that "even when the prerequisite assumptions do not precisely hold over the domains of the attributes, it may be a good approximation to assume they do" (9:298). Independence was a

factor in selecting the form of multiple attribute utility function used in this case study.

Several examples of multiple attribute utility analysis application are available in the literature. Three examples are cited here to highlight the broad and diverse subject material to which the analysis can be applied. Moskowitz, Evans and Jimenez-Lerma (16) explore options for expansion of electrical generation capability; Keeney and Raiffa (9) present a case study for development of airport facilities in Mexico City, Mexico; and Brown (2) considers criteria to determine technology priorities for research and development. In each case, a multiple set of diverse objectives is considered in a decision process of selecting a course of action with the highest expected utility.

Keeney and Raiffa (9) have compiled a very comprehensive treatise of the multiple objective decision problem with a generalized procedure for performing a structured decision analysis. This paper applies the procedure to demonstrate a multiple utility analysis for application of onboard simulation to operational flight training. Further explanation of the procedure is provided in conjunction with the analysis.

CHAPTER 3

THE VALUE OF OBS: IFFC PROGRAM EXPERIENCE

3.1 Software Development Savings

The most obvious method to establish an estimate of the value of OBS is to examine results of testing during the IFFC program. Cost savings which can be attributed to the presence of OBS can be identified and a total savings computed. An interesting fact was discovered which strongly indicates that OBS can directly reduce the cost of software development. According to Westermeir (22), the average or typical cost of software development for advanced development programs like IFFC is eight to ten manhours per word of software code. A final contract cost tabulation of the IFFC program revealed an average of only three and one-half manhours charged per word of software. This very significant difference is attributed to the presence of OBS for reasons discussed in the next paragraph.

Software development for the IFFC program involved use of a software test facility and man-in-the-loop simulation at the company facilities in St Louis, Missouri. Here, software was developed into an operational flight program for the flight test phase of the program. Initial airworthiness testing was also performed at St Louis, after which the aircraft was transferred to Edwards AFB, California, for 75 development flights. Throughout flight testing, the scftware test facility and simulator were used to support efforts to debug the flight software. The OBS model was used at all facili-

ties as a common baseline against which software performance could be tested. This common OBS link greatly increased the efficiency of effort between engineers at the three different facilities since anomalies could usually be repeated and quickly identified. Without OBS, a problem which is identified in flight test is often difficult to reproduce in support facilities. OBS also permitted engineers to themselves fly the weapon delivery encounters on the ground onboard the aircraft and quickly assess the impact of changes. This reduced dependence upon flight recordings or pilot comments to identify problems. Many problems were identified during OBS ground tests which otherwise would have been found in flight. Test flights were generally more successful than would be possible without OBS. Approximately 350 total software changes were performed during the 75 development flights.

A total of 33,000 words of software were developed for the IFFC flight program. Of this amount, 5,300 words were involved in OBS plus BATR and ACE scoring, leaving 27,700 words of IFFC fire and flight control. Using a cost of $60 per manhour, software cost savings due to the presence of OBS can be computed by comparing software cost at typical rates and at the reduced rate.

Typical software cost:

(27,700 words)(8 manhours/word)($60/manhour)= $13,296,000

NOTE: The value of eight manhours per word is the most conservative value in the range of eight to ten.

Cost with OBS:

(27,700 words)(3.5 manhours/word)($60/manhour)= $5,817,000

Cost Difference: $13,296,000 - $5,817,000 = $7,479,000

Costs incurred in the development of OBS shall now be subtracted from the savings in IFFC software development. In addition to the 5,300 words of software, an onboard simulation junction box was required for ground use of OBS, and a modification to the HUD processor was required for display of the new symbology.

OBS development cost:

(5,300 words)(3.5 manhours/word)($60/manhour)	=	$1,113,000
Junction box	=	10,000
Modification to HUD processor (3 sets)	=	90,000
Total	=	$1,213,000

The total net software savings attributed to OBS is computed as the difference between dollars saved and cost to develop OBS.

$7,479,000 - $1,213,000 = $6,266,000

3.2 Test and Evaluation Savings

OBS directly contributed to reduced cost of flight test and evaluation of the IFFC system in two ways. First, synthetic targets saved the expense of real targets and, second, more test events per flight could be performed using OBS. Definition of test modes is

warranted before attempting to estimate savings. Live-fire, tactical, and OBS testing was performed for each of the three weapon delivery modes (AAG, AGG, and BMG) giving a total of nine different conditions. Each condition is described as follows:

1. Live-fire AAG: An aerial tow target was towed behind an F-4 aircraft while the attacking F-15 aircraft fired live 20 millimeter ammunition, attempting to hit the tow target.
2. Tactical AAG: Aircraft such as T-38, F-106, and A-7 were flown as dynamic maneuvering targets for the attacking F-15. No bullets were actually fired, but onboard scoring was used to statistically model the expected number of hits.
3. OBS AAG: Synthetic target presented in HUD for F-15 attack. Expected hits were determined by onboard scoring.
4. Live-fire AGG: 20 millimeter ammunition was fired by the F-15 at stationary cloth banners which were anchored to the ground. Hits were scored by counting bullet holes in the banner.
5. Tactical AGG : Non-firing gun attack at cloth banners which were anchored to the ground. Expected hits were determined by onboard scoring.
6. OBS AGG : Non-firing gun attack against a stationary synthetic ground target. Expected hits were determined by onboard scoring.
7. Live-fire BMG : BDU-33 practice bombs were dropped by the F-15 on standard bombing range target. Miss distance was

measured by a survey of bomb impact relative to the range bullseye.

8. Tactical BMG : Bombing attack without bomb release against a standard bombing range target. Miss distance was estimated by onboard scoring.

9. OBS BMG : Bombing attack without bomb release against a synthetic ground target. Miss distance was estimated by onboard scoring.

A detailed summary of all encounters flown in the IFFC test program is presented in the Appendix. Data was obtained from individual flight reports from all 75 development flights (13). These data will be needed to estimate the test and evaluation savings directly attributed to OBS. Cost will be based on the 1983 fiscal year reimbursement rates which the Air Force Flight Test Center charged to the IFFC program. That is approximately $8,500 per F-15 or F-4 flight hour and $1,000 per T-38 flight hour. T-38 aircraft were used as target aircraft as much as possible because they provided fighter class performance at the lowest possible cost.

Additional information which will be needed is the average number of gun encounters performed per flight hour of live-fire, tactical, or OBS testing. Flights which were dedicated to each particular mode of interest were used to compute the averge values and are presented in Table 3-1. Flights which occurred very early in the program were not used in the estimates because test procedures were being perfected and pilot learning effects would bias the data.

Table 3-1

IFFC Flight Results

Mode	Average Flight Duration (Hr)	Average Events per Flight	Average Events per Flight Hour
Live-fire (air-to-air)	1.23	6.5	5.3
Tactical	1.48	24.3	16.3
OBS	1.38	53.0	39.8

From the Appendix, the total number of OBS test encounters can also be tabulated: 647 AAG, 191 AGG, and 137 BMG. Now OBS cost savings can be computed for each weapon mode.

3.2.1 Air-to-Air Gunnery

At an average of 40 OBS events per flight hour, 16.2 flight hours in the F-15 were needed to log 647 events.

(647 events)/(40 events/flight hour)= 16.2 flight hours

Total cost for 16.2 hours of F-15 time is $137,700.

(16.2 hours)($8,500/hour) = $137,000

If this many events had been performed in the tactical mode using a T-38 aircraft at an average of 16 events per flight hour, 40.4 flight hours would have been needed.

(647 events)/(16 events/flight hour)= 40.4 flight hours

The combined cost of an F-15 and T-38 per flight hour is $9,500, for a total of $383,800 for 40.4 flight hours. Net savings for using OBS is then the difference of $246,100. Remember that the inexpensive T-38 was used for a tactical target. If an F-15 had been used as a target, an even greater cost difference would have been experienced ($549,100).

3.2.2 Air-to-Ground Gunnery

For AGG, savings were accrued because more encounters were flown per hour than in the tactical mode. The 191 AGG encounters required 4.8 flight hours using OBS at a cost of $40,800.

(191 events)/(40 events/flight hour)= 4.8 flight hours

(4.8 flight hours)($8,500/flight hour)= $40,800

In a tactical mode, 11.9 flight hours would have been required at a cost of $101,150.

(191 events)/(16 events/flight hour) = 11.9 flight hours

(11.9 flight hours)($8,500/flight hour) = $101,150

OBS savings: $101,150 - $40,800 = $60,350

It has been assumed that onboard scoring can be used in the tactical AAG and AGG modes to determine hits on target. Without onboard scoring, live bullets would have been fired at an additional cost of $3,760 per flight (940 rounds @ $4.00 per round).

3.2.3 Bombing

In the BMG mode, 137 IFFC OBS encounters were performed. Again, savings are achieved using OBS because more encounters can be performed per flight hour. These 137 encounters required 3.4 flight hours at a cost of $28,900.

(137 encounters)/(40 encounters/flight hour)= 3.4 flight hours

(3.4 flight hours)($8,500/flight hour) = $28,900

Tactical bombing encounters would have required 8.6 flight-hours at $73,100.

(137 encounters)/(16 encounters/flight hour)= 8.6 flight hours

(8.6 flight hours)($8,500/flight hour) = $73,100

The OBS savings difference is $44,200.

$73,100 - $28,900 = $44,200

Again note that without onboard scoring, 137 practice bombs at $20 each would have cost an additional $2,740. Total test and evaluation savings due to OBS was $350,650.

$246,100 + $60,350 + $44,200 = $350,650

3.3 Total Savings

When software development and test and evaluation cost savings are combined, the total savings to the IFFC program was $6,616,650. Compared to the cost to develop OBS ($1,213,000), a savings of 5.5 times the development cost was realized. This is a very significant rate of return. Total cost for the IFFC program was approximately $25,000,000. Based on the computed savings, the program would have cost $31,616,650 or 26.5 per cent higher without OBS.

3.4 Additional Factors

In addition to the savings calculated so far, OBS contributed to the IFFC program in other more subtle ways which are difficult to measure in terms of dollars. Using the ground mode of OBS allowed pilots to "fly" encounters and familiarize themselves with symbology, switchology, encounter geometries, event sequences, expected performance, etc., before actual flight. System engineers could observe this ground training and work with the pilot to confirm everything was ready for flight. Without OBS, additional man-in-the-loop simulation and/or flight test would have been required.

For air-to-ground attack (AGG or BMG) risk of ground clobber is a major concern, especially in test programs. IFFC automatic control coupling between the flight and fire control systems was a new concept which created additional unknowns early in the flight test. Since OBS synthetic ground targets can be placed at any desired altitude, initial IFFC ground attack profiles were flown at safe altitudes until confidence in the IFFC system was established. Then actual ground targets were used. Value of this added safety is significant, but difficult to assign a dollar amount.

Some air-to-air gunnery conditions are difficult or unsafe to fly when using real target aircraft. Conditions approaching head-on or front quarter attack pose the potential of collision between the two aircraft. For this reason, most testing or operational flight training is restricted to aspect angles of 135 degrees or less (20). Onboard simulation can be safely used to test front-quarter attack because there is no risk of collision with the synthetic target. It

is important to be able to test systems or train in the front quarter because of studies which indicate a majority of combat encounters (where safety is less significant) would actually occur (19). OBS is very valuable when compared to the potential consequences of a mid-air collision.

CHAPTER 4

DEFINING THE DECISION PROBLEM

The previous chapter highlighted the value of OBS as a tool to support the flight test development of the IFFC weapon system. A natural question to ask at this point is, can OBS be successfully applied to the larger scale application of Air Force pilot training? Specifically, would OBS contribute to more affective and efficient pilot training in the air-to-air gunnery mission compared to current training methods?

4.1 Decision Alternatives

Several alternatives exist for how to apply OBS. The baseline for comparing alternatives will be current training methods without any changes. Onboard scoring can be implemented without OBS and vice versa. However, OBS without scoring is not considered a reasonable alternative because scoring is currently a problem which would continue with synthetic targets if scoring is not included. Current training augmented with only onboard scoring would be a reasonable alternative and shall be considered. Once OBS is installed in an aircraft, the relative amount of OBS training compared to live-fire and tactical training would be variable but the capital investment remains the same. Thus, a range of low to high percentage of OBS training shall be examined. Eight different alternatives shall be used in the analysis. They are defined as follows:

A1: Continue current operational training without any OBS features.

A2: Add only onboard scoring (BATR/ACE) to current training procedures.

A3: Include 1 OBS encounter for every 2 real encounters.

A4: Include 1 OBS encounter for every 1 real encounter.

A5: Include 2 OBS encounters for every 1 real encounter.

A6: Include 4 OBS encounters for every 1 real encounter.

A7: Include 6 OBS encounters for every 1 real encounter.

A8: Perform all gun training using OBS encounters.

The first important step is to develop a model of the current procedures for Air Force training in the air-to-air gun mode. Due to the difficulty of detailed record keeping, the Air Force does not record individual events or encounters which take place on training missions. Some assumptions and estimates are required to construct a model. Personnel from the Tactical Liaison Office at Wright-Patterson Air Force Base were instrumental in providing some necessary data for constructing the model and checking for reasonableness.

Most air-to-air gun training encounters are not performed on dedicated gun missions. Most often a mission will involve several training objectives such as missile encounters, formation flying, intercepts, and so on. Only live-fire missions against Dart targets are dedicated strictly to gun training. The approach is to start with a log of all missions flown in a one-year period and, based on the type of mission and typical mission breakdowns, estimate the

total number of gun events per year. Reference (21) lists all missions flown by 596 F-15 aircraft over a one-year period (June 1981 through June 1982). Only F-15 aircraft were considered in the model. Table 4-1 is a summary of missions flown and estimated gun encounters.

Important results from Table 4-1 were reviewed for a reasonableness check of the model. Each pilot receives approximately 245 gun training events per year, 25 live-fire and 220 tactical encounters, or roughly 90 percent tactical and 10 percent live-fire. This same ratio of tactical and live-fire encounters was used to define relative percentages in all alternatives. For example, alternative A-3 calls for one OBS encounter for every two real encounters. Ninety percent of the real encounters are assumed tactical, while ten percent are assumed live-fire.

4.2 Objectives and Measures of Effectiveness

Before evaluating alternatives, effectiveness measures need to be developed to form a basis of comparison. The overall objective of the comparison is to determine which of the eight possible alternatives provides the Air Force with the highest level of pilot training within reasonable cost and which is psychologically acceptable to pilots. A hierarchy of objectives is shown in Figure 4-1. Based on the hierarchy, six objectives were selected:

1. Minimize the average cost of training measured in dollars per gun event.

2. Provide the highest possible level of live-fire training which familiarizes pilots with gun system operation, confirms gun

TABLE 4-1

F-15 FLEET SUMMARY

TOTAL F-15 MISSIONS FLOWN FROM JUN 81 - JUN 82 = 119,712

596 TOTAL AIRCRAFT - 715 PILOTS

MISSION	% OF TOTAL MISSIONS	NUMBER OF MISSIONS	AVERAGE MISSION LENGTH	YEARLY MISSIONS PER PILOT	YEARLY MISSIONS PER A/C	GUN EVENTS* PER YEAR	YEARLY GUN EVENTS PER PILOT	YEARLY GUN EVENTS PER A/C
1 ACM W/GUNS	2.5	2,993	1.15	4.2	5.0	17,958	25.1	30.1
2 ACM W/MISSILE	37.0	44,293	1.21	61.9	74.3	79,727	111.5	133.8
3 INTERCEPT	13.0	15,563	1.26	21.8	26.1	28,013	39.2	47.0
4 ACM (CAMERA ONLY)	23.0	27,534	1.25	38.5	46.2	49,561	69.3	83.2
TOTAL	75.5	90,383	1.23	126.4	151.6	175,259	245.1	294.1
SUBTOTAL 2+3+4	73.0	87,390	1.23	122.2	146.6	157,301	—	—

* Assumes 6 events per mission for mission type 1

1.8 events per mission types 2, 3, 4

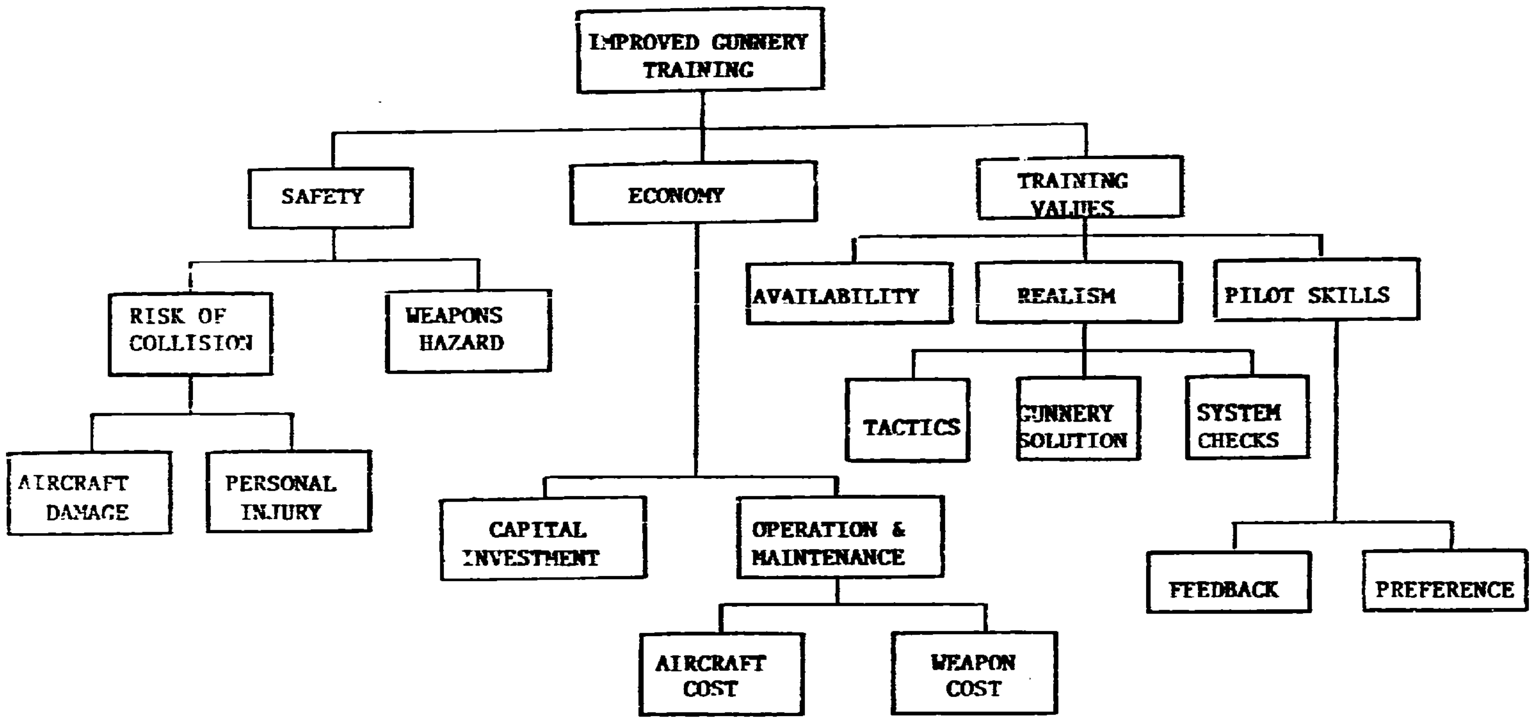


FIGURE 4-1

HIERARCHY OF OBJECTIVES

operability and gun boresight alignment. Number of live-fire missions per pilot per year is the measurement unit.

3. Maximize the effectiveness of training for weapon effectiveness; that is, training pilots where to aim and when to fire to score hits on target. Measured in terms of fractional effectiveness in representing actual combat conditions.

4. Maximize effectiveness of training for aircraft maneuvering tactics; train pilot in tactics which will allow him to maneuver into position for gunshot opportunity without self exposure. Measured in terms of fractional effectiveness in representing actual combat conditions.

5. Provide training psychologically acceptable to pilots; a minimum level of real encounters is desired by pilots after which OBS encounters can be flown. Measured as number of real encounters per pilot per year.

6. Maximize the availability of training based on the fraction of time when planned events can actually be performed.

Safety of training was considered as a separate objective, but safety restrictions affect the effectiveness of training in objectives 3 and 4. Thus, safety is indirectly considered.

CHAPTER 5

UTILITY FACTORS

5.1 Utility Function for Each Attribute

To proceed with the analysis, it is now necessary to establish preferences for the range of possible values for each attribute. Preferences are measured in units of utility, where utility is assigned values from zero to one. Maximum and minimum values of the attribute are to be selected which represent utilities of 1 and 0, respectively. Then attitudes of the decision maker toward risk establish the utility value over the attribute range, and a utility curve of all possible outcomes is defined. In this decision analysis, the decision maker is not any single individual, but rather the United States Air Force. For this reason, attitude toward risk is expected to be nearly neutral because individual tendencies toward risk aversion or risk proneness are averaged out. From the literature (9), risk neutral utility functions are typically linear and monotonically increasing toward the most desirable value of the attribute. One possible exception is the cost attribute where most decision makers tend to be risk averse (15, 18). A constantly risk averse exponential function is more appropriate here.

5.1.1 Cost Attribute (X_1)

An extensive background must be established before the cost utility function can be determined. This includes the statement of several assumptions used to derive cost figures.

1) a constant annual training budget is established for training Air Force pilots. Any investments in training devices, like OBS, are assumed to be taken from the existing budget.

2) Inflation effects are eliminated by assuming constant dollar value.

3) Capital investment in OBS is distributed into equal annual payments over a payback period of five years. The expected service life of OBS would be much longer, but a conservative approach is taken by keeping the payback to five years.

4) Payback is computed at an annual interest rate of 10 percent.

5) Cost of operation for F-15 or F-4 aircraft is $8,500 per flight hour, 20mm ammunition is $4.00 per round, and a Dart tow target is $200 per mission.

6) Estimated purchase cost of OBS is $12,000 per F-15 aircraft, if outfitting the entire fleet. The breakdown consists of $5,000 to modify a circuit card in the HUD and $7,000 for 5,300 words of software added to the aircraft central computer. All required documentation, such as changes to aircraft technical manuals and operating procedures, are included.

The baseline annual gun training budget must be defined before the relative cost of the eight decision analysis alternatives can be established. Since an official figure could not be found, a model was developed to estimate the annual cost of gun training. The cost of live-fire gunnery can be easily estimated because individual missions are dedicated to gun training and nothing else. Using information from Table 4-1:

Average flight time: 1.15 hour

Aircraft: One F-15 and one F-4 tow @ $8,500 per hour (each)

Cost: (2)($8,500/hour)(1.15 hour) = $19,500

Ammunition: (940 rounds)($4.00/round)= $3,760

Dart target: ($200/mission)

Total mission cost: $19,500 + 4,760 + 200 = $23,460

Cost per event: ($23,460/mission)/(6 events/mission)=($3,910/event)

Annual cost: (2,993 mission/year)($23,460/mission)=$70,215,780

Annual cost of tactical gun training is much harder to compute because missions are not dedicated to gun training. In Table 4-1, an assumption was made that F-15 pilots typically experience 1.8 gun encounters against each other during mission types 2, 3, and 4. These gun events are logged on the way to and from missile ranges or by maneuvering for a gun shot after a practice missile encounter has transitioned into a gun opportunity. Another way of stating this is that for every two F-15 flights , each pilot records an average of 1.8 gun encounters against the other F-15. Based on this assumption, a total of 157,301 tactical gun encounters were logged by 715 F-15 pilots over a one-year period. An equivalent number of dedicated tactical gunnery missions can be derived by dividing the total number of encounters by the average number of tactical encounters expected per mission from IFFC program experience, that is, 16 tactical gun events per flight hour. Since operational flights last an average of 1.25 flight hours, 20 tactical gun encounters are expected per flight.

(157,301 encounters)/(20 encounters/flight)=7,865.05 flights

Now the cost of 7,865.05 dedicated tactical gunnery flights can be computed. Note that an F-15 is used for target cost and not a T-38.

Average flight time: 1.25 hours

Aircraft: Two F-15 @ $8,500/hour each = ($17,000/hour)

Total mission cost: (1.25 hour)($17,000/hour) = $21,250

Cost per encounter:

($21,250/mission)/(20 encounters/mission)= ($1,062.50/encounter)

Yearly cost: (7,865.05 missions)($21,250/mission) = $167,132,310

Total yearly cost for live-fire and tactical F-15 gun training is $237,348,090.

$167,132,310 + 70,215,780 = $237,348,090

Although this total dollar amount is attributed to gun training, it also contributes to basic pilot flying skills and aircraft familiarization which eliminate the need for additional training flights. The $237,350,000 includes this prorated share of flying skills benefits which contributes to total pilot experience.

With the constant annual dollar amount established for gun training, the relative cost of the eight decision alternatives can be computed. Average cost per encounter will be the unit of comparison.

5.1.1.1 Alternative A1: For current training, the cost per encounter is determined by dividing the cost of training by the total number of encounters:

17,958 live-fire encounters + 157,301 tactical encounters =
175,259 total encounters

($237,348,090)/(175,259 encounters)= ($1,354.27/encounter)

5.1.1.2 Alternative A2: The investment cost for purchase of onboard scoring must be considered. An annual equivalent cost must be subtracted from the total available training budget. The cost of only onboard scoring is estimated at $2,000 per aircraft. A simple ratio comparing $7,000 for 5,300 words of OBS software with 1,300 words of scoring software gives a cost of $1,716. Assuming some slight overhead justifies a round-off to $2,000.

5,300 words/$7,000 = (1,300 words)/X
Where: X = $1,716 ≅ $2,000

At $2,000 per aircraft, total cost for 596 F-15s is:

($2,000)(596) = $1,192,000

Annual equivalent payment at i=10 percent interest over n=5 years is:

A=P (A/P, i, n) = (1,192,000)(0.2638) = $314,450

Where (A/P,i,n) is an equal-payment-series capital recovery factor (5). Subtracting from the total annual training budget gives:

$237,348,090 - $314,450 = $237,033,640

which is available for training after the payment for scoring. The number of encounters which can be flown is:

($237,033,640)/($1,354.27/encounter)= 175,027 encounters

Live encounters equal 10.25 percent of total (17,940)

Tactical encounters equal 89.75 percent of total (157,087)

Average cost per encounter is found by dividing the total training budget by the total number of encounters.

($237,348,090)/(175,029 encounters)= ($1,356.07/encounter)

5.1.1.3 Alternative A3: OBS with scoring is installed in each aircraft and one OBS gun encounter is flown for every two real (live-fire and tactical) encounters. Total cost of OBS is $12,000 for each of 596 aircraft.

($12,000)(596) = $7,152,000

Annual equivalent payback at i=10 percent interest over n=5 years is:

A=P (A/P, i, n) = (7,512,000)(0.2638)= $1,164,346

Subtracting from the annual training budget gives:

$237,348,090 - $1,164,346 = $236,183,744

which is available for training after the payment for OBS. Number and type of encounters are all computed using the cost of $212.50 per OBS encounter as computed previously.

[OBS cost]	=	[($212.5/event)x]
[tactical cost]	=	[(2x)(0.8975)($1,062.5/event)]
[live-fire cost]	=	[(2x)(0.125)($3,910/event)]
[total cost]	=	$236,183,744

Given that x = number of OBS events

Solving for x gives: x = 80,850 encounters

Simple substitution also identifies:

145,127 tactical encounters + 16,574 live-fire encounters =

242,551 total encounters

Average cost per encounter is found by dividing the total training budget by total encounters and gives:

($237,348,090)/(242,551 encounters)= $978.55/encounter

5.1.1.4 Alternatives A4 through A8: The same analysis method was used to compute options A4 through A8 and results for all alternatives are presented in Table 5-1. The annual equivalent cost for purchase of OBS is the same for all these alternatives. Only the ratio of OBS versus real encounters changes.

As can be seen from Table 5-1, cost ranges from a low of $213.55 per encounter for alternative A8 to a high of $1356.07 per encounter for alternative A2. From this, one could assume that a cost of $100 per encounter might have the highest utility (U(100) = 1) and if average cost grew to $2,000 per encounter, utility would be minimal (U(2,000) = 0). Using these boundary values, the endpoints of the cost utility function are defined. To determine the level of risk aversion, a certainty equivalent is determined based on a 50-50 lottery (100, 2,000) with an expected value of 1,050. A risk averse decision maker would accept for certain a value greater than the expected value, rather than risk the lottery. A certainty equivalent of 1,200 was selected as a representative value for slight risk aversion. By simple curve fit the exponential function, $U(X_1) = 2.036 - e^{0.000355(X_1)}$ fits the three data points and the utility function has been determined. Figure 5-1 is a graph of the function.

5.1.2 Live-Fire Gunnery Attribute (X_2)

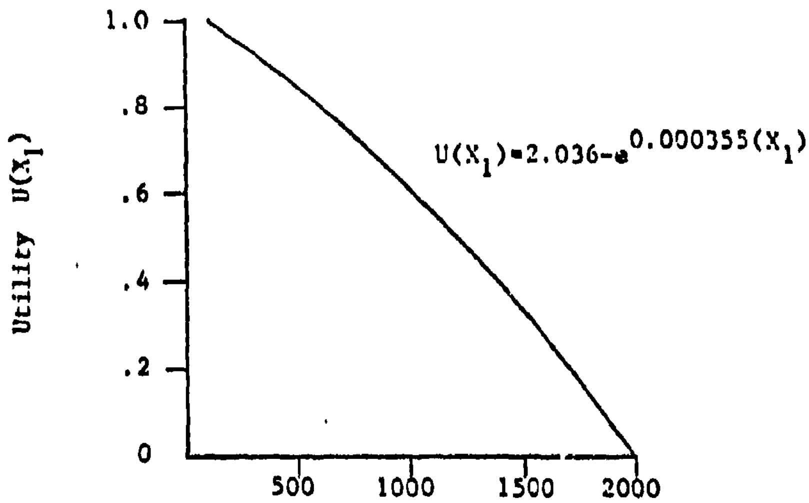
It was previously determined that F-15 pilots currently average approximately four live-fire training missions per year or 24 encounters. For experienced pilots, this is enough to maintain live gunnery proficiency. Inexperienced pilots might be able to use a few more encounters to improve their skills. Therefore, six missions per year

TABLE 5-1

TRAINING MIX FOR DECISION ALTERNATIVES

ALTERNATIVE	LIVE GUNNERY		TACTICAL		ONBOARD SIM		TOTAL EVENTS	COST* / EVENT	TOTAL FLIGHTS
	EVENTS	FLIGHTS	EVENTS	FLIGHTS	EVENTS	FLIGHTS			
A1	17,958	2993	157,301	7865	-	-	175,259	$1354.27	10,858
A2	17,940	2990	157,086	7854	-	-	175,027	$1356.07	10,844
A3	16,574	2762	145,127	7256	80,850	1617	242,551	$ 978.55	11,635
A4	15,450	2575	135,286	6764	150,736	3015	301,472	$ 787.30	12,354
A5	13,605	2268	119,129	5956	265,470	5309	398,204	$ 596.05	13,533
A6	10,982	1830	96,161	4808	428,574	8571	535,717	$ 443.05	15,209
A7	9,207	1534	80,618	4031	538,952	10,779	628,777	$ 377.48	16,344
A8	-	-	-	-	1,111,453	22,229	1,111,453	$ 213.55	22,229

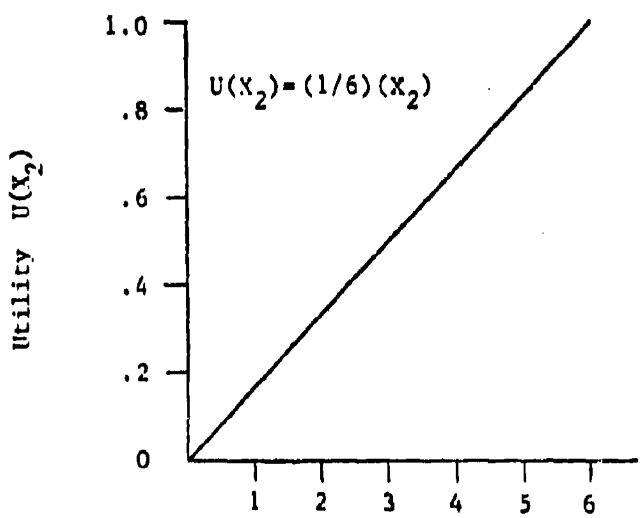
* BASED ON TOTAL TRAINING BUDGET OF $237,348,090.00.



X_1= Cost per Gun Event

FIGURE 5-1

X_1 UTILITY FUNCTION



X_2= Live-Fire Missions per Year

FIGURE 5-2

X_2 UTILITY FUNCTION

is selected as the most desirable average with a utility of 1.0. No encounters per year obviously would not contribute to pilot skills or help confirm gun system operation and is assigned a utility of zero. Assuming a linear, risk neutral function fully determines the utility function as $U(X_2) = (1/6)(X_2)$ (see Fig 5-2).

5.1.3 Gunnery Solution Effectiveness Attribute (X_3)

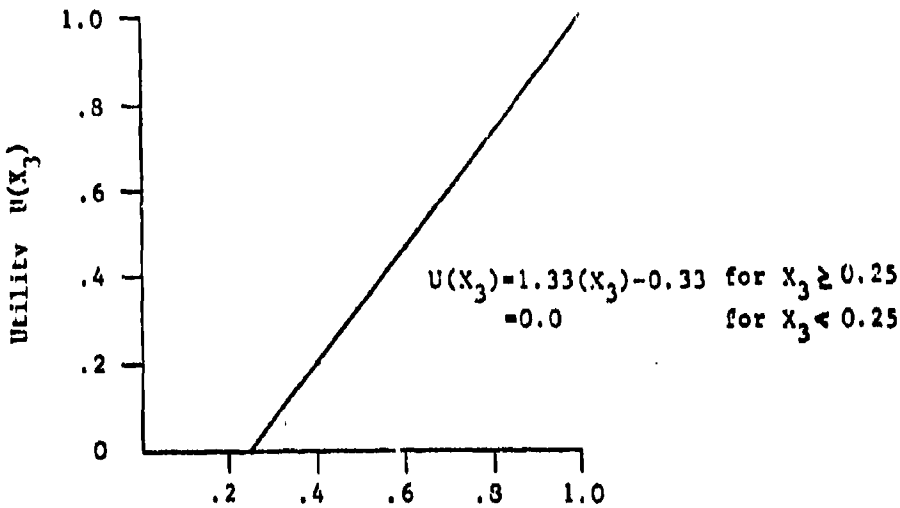
If training were totally effective in teaching pilots how to fly the aircraft to the proper aim point to get bullets on target, this attribute would have a utility of one. However, a utility of zero is assumed to be reached before the training reaches an effectiveness of zero. It is probable that if training is only 25 percent effective, then the utility is zero. Again, a constant neutral risk linear equation through these endpoints defines the utility function as $U(X_3) = 1.33(X_3) - 0.33$ as depicted in Figure 5-3.

5.1.4 Gunnery Tactics Effectiveness Attribute (X_4)

The utility function chosen for tactics effectiveness follows the same logic as gunnery solution effectiveness. A utility of one is assigned if the training teaches pilot air combat maneuvering tactics which are representative of actual combat conditions. If training becomes only 25 percent effective, the utility is assumed zero. Thus, $U(X_4) = 1.33(X_4) - 0.33$ as shown in Figure 5-4.

5.1.5 Real Gunnery Events per Year Attribute (X_5)

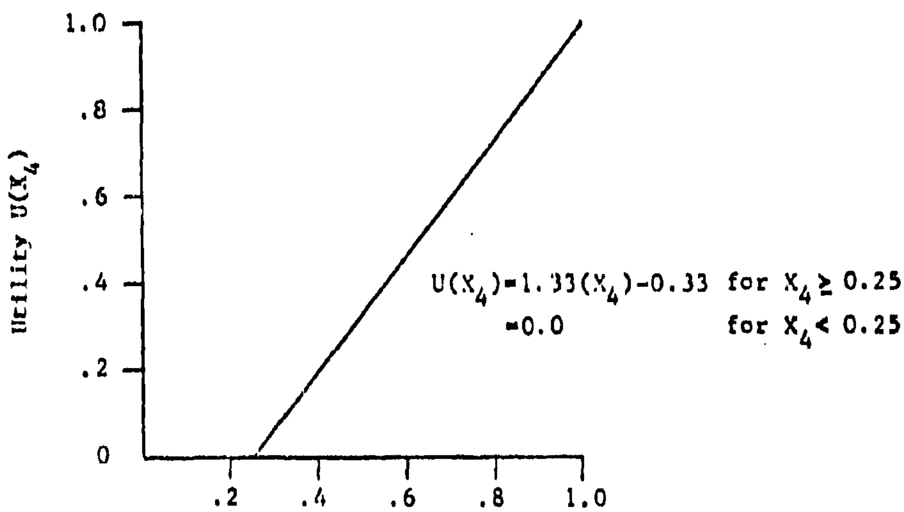
Most pilots seem willing to accept OBS as an alternate form of training, but on the condition that a significant amount of real encounters are continued. OBS is seen as a way of augmenting training, but not a substitute for air combat maneuvering against other



X_3 = Gunnery Solution Effectiveness

FIGURE 5-3

X_3 UTILITY FUNCTION



X_4 = Gunnery Tactics Effectiveness

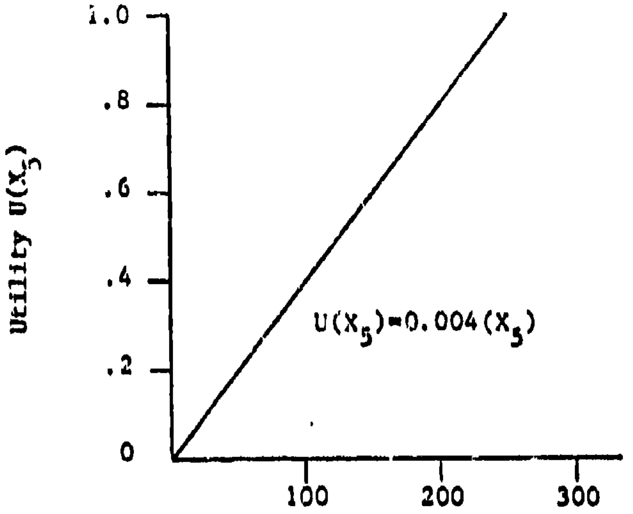
FIGURE 5-4

X_4 UTILITY FUNCTION

pilots to refine one's competitive edge. As computed previously, pilots now average approximately 245 real encounters per year. A utility of one is assigned to 250 real encounters which decreases to zero utility at zero real encounters. The utility function depicted in Figure 5-5 is $U(X_5) = 0.004(X_5)$.

5.1.6 Availability of Training Attribute (X_6)

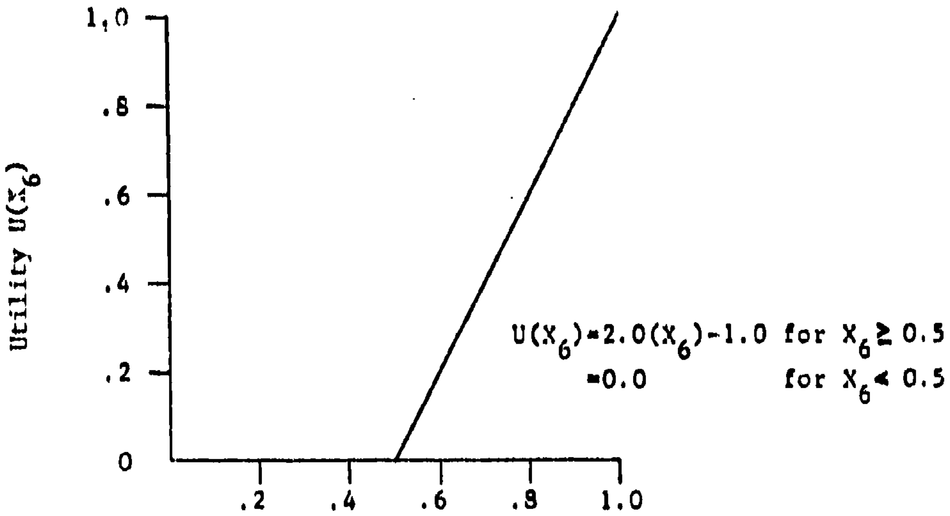
Availability of training is related to reliability or the probability of achieving any scheduled training session. In the case of OBS, only one aircraft is required to become airborne to perform the OBS training. For tactical training, two aircraft must be airborne simultaneously, and a target must be added with its associated probability for live-fire training. If 100 percent probability of achievement were possible, this would have a utility of one. Zero utility may be realized if this probability were to sink to 0.5. The resulting utility function shown in Figure 5-6 is $U(X_6) = 2(X_6) - 1.0$. A summary of attribute characteristics is presented in Table 5-2.



X_5= Real Gunnary Events/Year

FIGURE 5-5

X_5 UTILITY FUNCTION



X_6= Availability

FIGURE 5-6

X_6 UTILITY FUNCTION

Table 5-2

SUMMARY OF ATTRIBUTES

ATTRIBUTE	MEASUREMENT UNIT	RANGE
X_1: Cost	Dollars per encounter	100-2000
X_2: Live-fire	No. of live-fire missions/pilot/year	0-6
X_3: Gunnery Solution	Effectiveness	0.25-1.0
X_4: Gunnery Tactics	Effectiveness	0.25-1.0
X_5: Pilot Preference	No. of real encounters/pilot/year	0-250
X_6: Availability	Probability of training mission	0.5-1.0

5.2 Individual Utility Factor Values

Now that the eight alternatives and six attributes with utility functions have been identified, only one task remains before the utility analysis can proceed. The remaining task is to assign a specific attribute value of all six attributes to each alternative. This will create a total of 48 attribute values from which utility factors are determined.

5.2.1 X_1 Utility Factors

To begin, a cost per encounter must be assigned to each of the eight alternatives. Cost was determined previously and shown in Table 5-1. Each cost value is used as an independent variable in the exponential utility function, $U(X_1) = 2.036 - e^{0.000355(X_1)}$, and solved for $U(X_1)$. Results are shown in Table 5-3.

5.2.2 X_2 Utility Factors

The number of live-fire missions, attribute X_2, was also computed for each alternative in Table 5-1. Utility function $U(X_2) = (1/6)X_2$ is used to compute the utility $U(X_2)$ for each alternative. One correction factor was applied to the number of live-fire missions. Current training methods (alternative A1) suffer from a lack of knowledge of miss distance for those firing bursts when no hits are seen hitting the Dart target. Onboard scoring would eliminate this deficiency by letting the pilot know where his bullet stream should have gone relative to the target. If hits are predicted but the Dart remains untouched, a gun alignment problem should be suspected. Since alternative A1 was the only alternative without scoring, credit was given for only one-half of the live-fire missions, that is, 2.1 missions instead of 4.2.

Table 5-3

Utility Factors for X_1

Alternative	Cost per Encounter (X_1)	Utility $U(X_1)$
A1	1354.27	0.42
A2	1356.17	0.42
A3	978.55	0.62
A4	787.30	0.71
A5	596.05	0.80
A6	443.05	0.87
A7	377.48	0.89
A8	213.55	0.96

Table 5-4

Utility Factors for X_2

Alternative	No. of Live-Fire Missions (X_2)	Utility $U(X_2)$
A1	2.7	0.35
A2	4.2	0.70
A3	3.9	0.65
A4	3.6	0.60
A5	3.2	0.53
A6	2.6	0.43
A7	2.1	0.35
A8	0	0.00

5.2.3 X_3 Utility Factors

Assessment of gunnery solution effectiveness requires subjective analysis of several factors. Remember that (1) tactical training encounters are restricted to less than 135 degrees aspect angle for safety purposes, (2) current LCOS gunsights in the F-15 require lead angle at target aspect angles greater than 40 degrees, and (3) expected gun opportunities are 54 percent front quarter, 23 percent beam quarter (side), and 23 percent rear quarter (19). Current training alternative (A1) in tactical mode with manned target aircraft uses pipper on target as criteria for scoring a kill (19). Since this technique is only correct in the rear quarter, the training is only effective for use in combat for the rear quarter where 23 percent of the opportunities exist. Some slight additional credit is given due to bullet dispersion and tracking errors which will sometimes help with getting hits on target. An effectiveness rating of 0.3 is assigned to A1.

The addition of onboard scoring in alternative A2 certainly improves the effectiveness of training because the pilot gets real-time feedback of where his bullet stream went relative to the target. BATR on target can replace pipper on target as scoring criteria during training. Scoring according to where the bullets went is much more realistic than pipper on target. The safety restriction of 135 degree aspect angle still restricts training where 50 percent of gun opportunities exist. An effectiveness rating of 0.5 is assigned to A2.

Alternatives A3 through A8 include increasing amounts of OBS training which does permit testing at all aspect angles, including the

front quarter, because there is no risk of collision with the synthetic target. It is recommended, however, that OBS encounters remain mixed at various aspect angles and not limited only to front quarter encounters. This is because if the pilot knows OBS targets are always front quarter, he will learn the game and anticipate the maneuvers, which is less than realistic. If a mix of OBS encounters is used, then the pilot would have to react to the particular situation which is much more realistic. With a small fraction of OBS encounters, some of the front quarter void is filled in. As a larger percentage of OBS is included, a balance can be struck where enough encounters are flown to fill the front quarter void and still maintain sufficient real encounters to compensate for less than perfect realism in the synthetic target model. This balance is assumed to occur at a ratio of four OBS encounters for every one real encounter (alternative A6). A peak effectiveness rating of 0.9 was assigned simply because a training situation will never fully represent actual combat. Even though OBS can be used at all aspect angles, alternative A8, all OBS and no real, was reduced to 0.8 effectiveness to account for target model realism. A summary of X_3 attribute values is shown in Table 5-5 with resulting utility from $U(X_3) = 1.33(X_3) - 0.33$.

Table 5-5

Utility Factors for X_3

Alternative	Gunnery Solution Effectiveness (X_3)	Utility $U(X_3)$
A1	0.3	0.06
A2	0.5	0.33
A3	0.6	0.47
A4	0.7	0.60
A5	0.8	0.73
A6	0.9	0.87
A7	0.85	0.80
A8	0.80	0.73

Table 5-6

Utility Factors for X_4

Alternative	Gunnery Tactics Effectiveness (X_4)	Utility $U(X_4)$
A1	0.6	0.47
A2	0.6	0.47
A3	0.75	0.67
A4	0.9	0.87
A5	0.8	0.73
A6	0.6	0.60
A7	0.4	0.20
A8	0.25	0.00

5.2.4 X_4 Utility Factors

Pilot knowledge of air combat maneuvers is important in creating the positional advantage needed to develop a gun shot opportunity while denying the adversary opportunities. Here, the relative positioning against the target, or tactics, are most important. Lead angle requirements of the gunsight are not a direct factor as for the previous gun solution attribute X_3, but again, front quarter safety restrictions are a factor. Tactical encounters with manned maneuvering targets are generally better than OBS, at less than 135 degrees aspect angle, because of HUD field-of-view limitations in OBS. In the front quarter OBS can be somewhat effective since head-on encounters with maneuvering can be performed within the field-of-view. Current training (A1) is assigned an effectiveness of 0.6. Alternative A2 remains 0.6 because scoring does nothing to improve tactics. It is assumed that the best balance is achieved with two OBS encounters for every one real with effectiveness at 0.9. Then effectiveness continues to decline as more and more OBS is included until alternative A8, all OBS, is assigned an effectiveness of 0.25. Applying utility function $U(X_4)=1.33(X_4)-0.33$ gives results shown in Table 5-6.

5.2.5 X_5 Utility Factors

Pilot preference for a training curriculum which contains a core of real encounters is a significant factor. This places OBS into a training augmentation role rather than a replacement of current training methods in the mind of the pilot. In Table 4-1, the number of real encounters per pilot per year was presented for each of the eight alternatives. Utility factors are computed from $U(X_5) = 0.004(X_5)$ as shown in Table 5-7.

Table 5-7

Utility Factors for X_5

Alternative	No. of Real Encounters (X_5)	Utility $U(X_5)$
A1	245	0.98
A2	245	0.98
A3	226	0.90
A4	211	0.84
A5	186	0.74
A6	150	0.60
A7	126	0.50
A8	0	0.00

Table 5-8

Utility Factors for X_6

Alternative	Availability (X_6)	Utility $U(X_6)$
A1	0.79	0.58
A2	0.79	0.58
A3	0.81	0.62
A4	0.82	0.64
A5	0.84	0.67
A6	0.85	0.70
A7	0.86	0.72
A8	0.90	0.80

5.2.6 X_6 Utility Factors

Availability of training can be improved with application of OBS because no target aircraft is required. If the probability of an aircraft takeoff is 0.9, then the probability of two aircraft is 0.81. Although specific F-15 mission reliability data could not be found, an assumed 0.9 value is used since the relative difference is important and not the specific value. Adding OBS to the F-15 would not degrade mission reliability because OBS is primarily software in the central computer which must be operational for any training mission. OBS training missions are assigned a probability of 0.9 while tactical missions, which require two aircraft, are assigned a probability of 0.81. Live-fire encounters also require a Dart tow target which is assumed to erode combined probability to a value of 0.75. Each alternative is assigned a probability based on the relative percentage of OBS, live-fire, and tactical encounters. Availability obviously improves as more OBS is used until a maximum 0.9 is reached with all OBS. Utility is determined from $U(X_6) = 2(X_6) - 1.0$ as shown in Table 5-8.

The utility factors have now been assembled for all alternatives and attribute combinations. A complete matrix of the 48 utility factors is presented in Table 5-9. Decision analysis solutions will be performed in the next chapter.

TABLE 5-9

MATRIX OF UTILITY FACTORS

ALTERNATIVE	ATTRIBUTE					
	X_1	X_2	X_3	X_4	X_5	X_6
A1	0.42	0.35	0.06	0.47	0.98	0.58
A2	0.42	0.70	0.33	0.47	0.98	0.58
A3	0.62	0.65	0.47	0.67	0.90	0.62
A4	0.71	0.60	0.60	0.87	0.84	0.64
A5	0.80	0.53	0.73	0.73	0.74	0.67
A6	0.87	0.43	0.87	0.60	0.60	0.70
A7	0.89	0.35	0.80	0.20	0.50	0.72
A8	0.96	0.00	0.73	0.00	0.00	0.80

CHAPTER 6

MULTIATTRIBUTE DECISION ANALYSIS

6.1 Form of the Utility Function

The general form of the utility function assuming attribute independence, as defined by Keeney and Raiffa (9:454) is:

$$K[U(X_1, X_2, \ldots, X_6)] + 1 = \prod_{i=1}^{6} [K(K_i)(U_i)(X_i) + 1] \quad \text{Equation 6-1}$$

where the individual $U_i X_i$ were determined in Chapter 4. That is, the 48 values of six attributes versus eight alternatives. The K_i terms are scaling factors for U_i, with values between 0 and 1, and K is another scaling constant.

6.2 Assessing the K_i Scaling Factors

The procedure for assessing the K_i scaling factors is subjective in that decision maker opinion determines the relative importance between the attributes. Since no one individual can provide an undisputed Air Force opinion, the analysis was performed in the following manner. First, the analysis is performed using the opinion of the author, an aerospace engineer, to determine the scaling factors. Then the analysis is repeated using the opinions of a cross section of individuals to determine the effects of diverse opinions upon the analysis. Various backgrounds such as engineers, managers, current pilots, and former pilots were sampled.

To begin, the attributes must be ranked in order 1 through 6 for level of importance. The first choice is made by selecting the one

attribute which would be at its most preferred level while all others are at their least preferred level. The author selected gunnery solution effectiveness, attribute X_3, as the one most desirable. Logic for this choice was, if a pilot is not trained to hit a target that is presented to him, then nothing else matters. Another choice is made from the remaining five attributes, X_4 gunnery tactics was selected as the second ranked attribute. Repeating this procedure resulted in the ranking indicated in Table 6-1.

Now the quantitative values of the scaling factors must be determined. The attribute ranked first (X_3 in the author's example) is paired with each remaining attribute. For each pair, the decision maker determines at what level of the first ranked attribute would he be indifferent to the most desirable level of the other attribute (with all other attributes at convenient levels). For example, if gunnery tactics effectiveness X_4 was rated at its best possible level (1.0), at what level of gunnery solution effectiveness X_3 would you be indifferent between the pair? The author selected 0.95 as the value of X_3 where he would be indifferent to selecting X_4 at its highest level.

$$1.0\ X_4 \sim 0.95\ X_3$$

An indifference value of 0.95 means attribute X_4 is almost equally important at X_3. As the indifference value decreases, the paired attribute is of lesser relative importance. Indifference equivalents are established for all remaining attributes in a similar fashion. Results are presented in Table 6-1.

TABLE 6-1

SCALING FACTORS FOR ATTRIBUTES

Attribute	Relative Ranking of Scaling Factor	Range	Indifference Equivalent	Scaling Factor	Scaling Factor
X_1: Cost	3	2000-100	$100X_1 \sim 0.8X_3$	$K_1 = 0.73K_3$	0.55
X_2: Live fire exp.	5	0-6	$6X_2 \sim 0.5X_3$	$K_2 = 0.33K_3$	0.25
X_3: Gun Solution Eff	1	0.25-1.0	-	K_3	0.75
X_4: Tactics value	2	0.25-1.0	$1.0\,X_4 \sim 0.95X_3$	$K_4 = .93K_3$	0.70
X_5: Pilot preference	4	0-250	$250X_5 \sim 0.7X_3$	$K_5 = 6.0K_3$	0.45
X_6: Availability	6	0.5-1.0	$1.0X_6 \sim 0.4X_3$	$K_6 = .2K_3$	0.15
					2.85

ASSUME: $K_3 = P = 0.75$

Using the utility function for the most important attribute (X_3) the relative scaling factors can be determined. Assigning K_3 as the scaling factor for X3, each relative scaling factor K_i, i = 1 to 6, is calculated as follows:

Let X_i = the indifference equivalent for the ith attribute

Then $K_i = 1.33(X_i) - 0.33$ (the first ranked utility function)

Continuing the procedure for the ongoing example;

$X_4 = 0.95$

$K_4 = 1.33\ (0.95) - 0.33 = 0.93$

Relative scaling factors for all attributes are presented in Table 6-1.

Finally, each relative scaling factor must be multiplied by a selected value of K_3. The results are the new K_i values, the actual scaling constants for each attribute. Here, the decision maker must make a difficult selection to the following question: for what probability P, would you be indifferent between option 1 with the first priority attribute at its highest level and all other attributes at their least desirable levels, and an alternative option 2 consisting of all attributes at their most desirable level with probability P or otherwise at their worst desirable level? An illustration of the two options, using author opinions is depicted in Figure 6-1.

The value of P will increase toward a value of 1.0 if the decision maker (author) feels that gunnery effectiveness dominates the other

OPTION 1

GUNNERY SOLUTION EFFECTIVENESS
AT COMPLETE EFFECTIVENESS (1.0)

AND

ALL OTHER ATTIBUTES AT WORST
LEVELS

OPTION 2

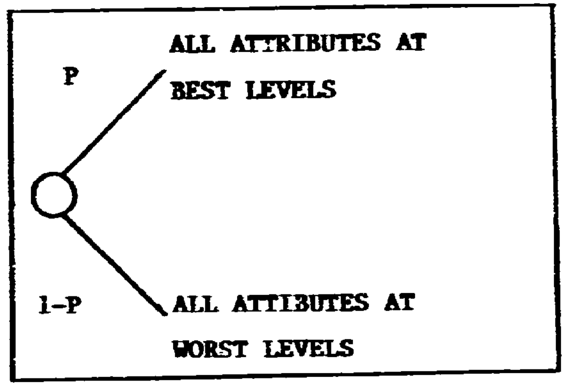


FIGURE 6-1

SCALING FACTOR DECISION OPTIONS

attributes. If less dominant, then P will approach zero. A P value of 0.75 was selected by the author. Confidence in the selection of P is not extremely high. Therefore, the analysis will be repeated using various values of P to establish the level of sensitivity. Substituting P = 0.75 for the value of K_3 fully determines the magnitude of the K_i scaling factors as shown in Table 6-1.

The value of K is determined by evaluating the general form utility function at the attribute's most preferred values. From the scaling convention used on the individual attribute utility functions U_iX_i and composite utility function $U(X_1, X_2, \ldots X_6)$, all utilities are equal to 1. This reduces the general form utility equation to

$$K+1 = (K(K_1) + 1)(K(K_2) + 1)\ldots(K(K_6 + 1)) \quad \text{Equation 6-2}$$

Since all K_i terms are known, the value of K can be solved by an iterative process. Using author data, the value of K is found to be -.987 for the example.

6.3 Expected Utility

All required information is now available to solve the general utility function (Eqn 6-1) for each of the eight alternatives. The preferred alternative should be the one with the highest expected utility. Results for author data are shown in Table 6-2.

From the expected utilities, the highest three alternatives are nearly equal. This is not a significant problem because these alternatives all contain a mix of onboard simulation. A decision to purchase OBS as a training device would be recommended over the other options.

Table 6-2

Author Expected Utilities

Alternative	Expected Utility
A1: Current Training	0.78
A2: Current Training plus Onboard Scoring	0.84
A3: 1 OBS for every 2 real encounters	0.91
A4: 1 OBS for every 1 real encounter	0.95
A5: 2 OBS for every 1 real encounter	0.94
A6: 4 OBS for every 1 real encounter	0.95
A7: 6 OBS for every 1 real encounter	0.90
A8: All OBS encounters	0.82

Current training methods or adding only onboard scoring to current training are not as effective. An average of approximately two OBS encounters for every real encounter would be recommended. This would equate to 1.3 dedicated real flights to every OBS flight. Total conversion to OBS training would not be desirable.

6.4 Sensitivity Analysis

Before placing too much emphasis on the previous results, some further analysis is warranted. Previous concern was expressed in the lack of confidence in the selection of probability P when determining the scaling factors for the six attributes. Values for P ranging from 0.0 to 1.0 could have been used, with the author selecting 0.75. The analysis was recomputed for P set at 0.2, 0.4, 0.6 and 0.8 to determine effects on the final results. Table 6-3 shows the various results.

It is apparent that the analysis is not very sensitive to changes in P. Slight differences appear in the relative magnitude of alternatives A1 and A8, but alternatives A4, A5, and A6 maintain the highest expected utility factors.

6.5 Individual Decision Makers

Additional concern is raised over the sensitivity of the analysis to preferences of individuals who may not agree with opinions of the author. An Air Force pilot who is current in F-15 aircraft has different perspectives which might result in significantly different ranking and scaling of decision attributes. As a precaution, several persons with differing backgrounds were interviewed as decision makers. The analysis was repeated using the scaling factors assigned

TABLE 6-3

EXPECTED UTILITY SENSITIVITY TO P

ALTERNATIVE	EXPECTED UTILITY			
	P = .2	P = .4	P = .6	P = .8
A1	0.33	0.55	0.69	0.80
A2	0.40	0.64	0.77	0.86
A3	0.49	0.74	0.85	0.92
A4	0.55	0.82	0.90	0.96
A5	0.55	0.81	0.90	0.96
A6	0.54	0.81	0.90	0.96
A7	0.44	0.70	0.83	0.92
A8	0.32	0.56	0.72	0.84

by each subject. A brief background of each subject is presented below, followed by Table 6-4 through 6-9 which present decision variables for each individual subject.

Subject No. 1: Air Force Colonel who is currently a three-letter symbol chief in a research and development laboratory. Holds a PhD in Aerospace Engineering. Pilot experience as a forward air controller and in C-141 transport.

Subject No. 2: Air Force Major currently assigned to the Tactical Air Command as a liaison officer. Holds a Masters degree in Business Administration. Pilot experience includes 2,000 hours in the F-4 aircraft.

Subject No. 3: Air Force Major currently assigned to the Director of Operational Requirements at Headquarters, United States Air Force. Holds a Bacholor of Science degree in Aerospace Engineering and a Masters degree in Business Administration. Pilot experience includes 3,000 hours in F-4 and, most recently, F-15 aircraft. Also flew as test pilot in gunsight development program.

Subject No. 4: Air Force Captain currently assigned as Test Director of a research and development program investigating air-to-air gunnery technology. Holds a Bachelor of Science degree in Aerospace Engineering. Flight experience includes 1,200 hours as an F-4 weapon system officer.

Subject No. 5: Air Force Major currently assigned to the Tactical Air Command as a liaison officer. Holds a Masters degree and has 2,900 hours as the pilot of an F-4 aircraft.

Subject No. 6: Air Force Major currently assigned to the Tactical Air Command as a liaison officer. Holds a Bachelor of Science degree in Electrical Engineering and a Masters degree in Business Administration. Flight experience includes 2,000 hours as an F-4 weapon system officer.

In summary, the decision makers sampled in this study included an engineer (author), an engineering manager (Subject 1), an F-15 pilot (Subject 3), two F-4 pilots (Subjects 2 and 5), and two F-4 weapon system officers (Subjects 4 and 6). Results of the decision variables selected by these subjects are presented in the summary chapter.

TABLE 6.4

SUBJECT NO. 1 DECISION VARIABLES

ATTRIBUTE	RANK ORDER	INDIFFERENCE EQUIVALENT
X_1: COST	4	0.9
X_2: LIVE FIRE EXPERIENCE	6	0.5
X_3: GUN SOLUTION EFFECTIVENESS	1	-
X_4: TACTICS EFFECTIVENESS	5	0.8
X_5: PILOT PREFERENCE	2	0.95
X_6: AVAILABILITY	3	0.94

$P = 0.55$

TABLE 6.5

SUBJECT NO. 2 DECISION VARIABLES

ATTRIBUTE	RANK ORDER	INDIFFERENCE EQUIVALENT
X_1: COST	6	0.05
X_2: LIVE FIRE EXPERIENCE	5	0.15
X_3: GUN SOLUTION EFFECTIVENESS	1	-
X_4: TACTICS EFFECTIVENESS	2	0.95
X_5: PILOT PREFERENCE	4	0.85
X_6: AVAILABILITY	3	0.94

$P = 0.75$

TABLE 6.6

SUBJECT NO. 3 DECISION VARIABLES

ATTRIBUTE	RANK ORDER	INDIFFERENCE EQUIVALENT
X_1: COST	6	0.30
X_2: LIVE FIRE EXPERIENCE	3	0.92
X_3: GUN SOLUTION EFFECTIVENESS	2	0.95
X_4: TACTICS EFFECTIVENESS	1	-
X_5: PILOT PREFERENCE	4	0.85
X_6: AVAILABILITY	5	0.80

$p = 0.75$

TABLE 6.7

SUBJECT NO. 4 DECISION VARIABLES

ATTRIBUTE	RANK ORDER	INDIFFERENCE EQUIVALENT
X_1: COST	5	0.70
X_2: LIVE FIRE EXPERIENCE	3	0.96
X_3: GUN SOLUTION EFFECTIVENESS	2	0.98
X_4: TACTICS EFFECTIVENESS	1	-
X_5: PILOT PREFERENCE	6	0.60
X_6: AVAILABILITY	4	0.75

$P = 0.35$

TABLE 6.8

SUBJECT NO. 5 DECISION VARIABLES

ATTRIBUTE	RANK ORDER	INDIFFERENCE EQUIVALENT
X_1: COST	4	0.75
X_2: LIVE FIRE EXPERIENCE	6	0.30
X_3: GUN SOLUTION EFFECTIVENESS	1	-
X_4: TACTICS EFFECTIVENESS	2	0.95
X_5: PILOT PREFERENCE	5	0.50
X_6: AVAILABILITY	3	0.80

$\rho = 0.7$

TABLE 6.9

SUBJECT NO. 6 DECISION VARIABLES

ATTRIBUTE	RANK ORDER	INDIFFERENCE EQUIVALENT
X_1: COST	2	0.95
X_2: LIVE FIRE EXPERIENCE	6	0.30
X_3: GUN SOLUTION EFFECTIVENESS	4	0.80
X_4: TACTICS EFFECTIVENESS	3	0.85
X_5: PILOT PREFERENCE	5	0.60
X_6: AVAILABILITY	1	-

$P = 0.8$

CHAPTER 7

SUMMARY

7.1 Review of Decision Maker Responses

Of the seven individual decision makers sampled in this study, each gave a different rank order to the six attributes. Table 7-1 is a summary of the responses for the author and six other subjects. A consolidation of the results provides some apparent trends. For instance, gun solution effectiveness (attribute X_3) was selected as the first-ranked attribute by four of the subjects. Tactics effectiveness (X_4) received top ranking two times and availability (X_6) once. Cost (X_1), live fire experience (X_2) and number of tactical encounters (X_5) were never ranked first. The relative importance of the attributes can be established by adding the seven rank values assigned to each attribute. Thus, the most important attribute is the one with the fewest points, and the least important has the most points. Results are shown in Table 7-1. As expected, gun solution effectiveness (X_3) finished first, followed in order by tactics effectiveness (X_4), availability (X_6), cost (X_1) tied with number of tactical encounters (X_5) and live-fire experience (X_2). These attribute rankings indicate the attitudes of the decision makers concerning the most important characteristics of air-to-air gunnery training. However, the final goal of this study is to determine which of the eight decision alternatives should be selected. Therefore, the decision analysis is repeated using the scaling factors which result from each individual to determine the expected utility of the alternative.

TABLE 7-1

SUMMARY OF SUBJECT RANKINGS

ATTRIBUTE	RANK ORDER FOR SUBJECT							TOTAL POINTS	AVERAGE RANK	NO. OF FIRST RANKINGS
	A	1	2	3	4	5	6			
X_1: COST	3	4	6	6	5	4	2	30	4.3	0
X_2: LIVE FIRE EXPERIENCE	5	6	5	3	3	6	6	34	4.8	0
X_3: GUN SOLUTION EFFECTIVENESS	1	1	1	2	2	1	4	12	1.7	4
X_4: TACTICS EFFECTIVENESS	2	5	2	1	1	2	3	16	2.3	2
X_5: PILOT PREFERENCE	4	2	4	4	6	5	5	30	4.3	0
X_6: AVAILABILITY	6	3	3	5	4	3	1	25	3.6	1

7.2 Expected Utilities

Table 7-2 is a summary of the expected utilities of the eight alternatives which were computed for each decision maker. A review of each alternative is presented. Alternative A1, the current form of training, received the lowest expected utility value in of the seven cases, and had the lowest average utility. This strongly indicates that OBS can improve the quality of flight training. However, OBS is not without drawbacks, as evidenced by the consistently low utility values for alternative A8 which would convert all training to OBS. Alternative A8 had the lowest utility value in two of the seven cases and average utility only slightly higher than alternative A1. It is apparent that the best alternative must be a balance of OBS and "real" training. Addition of only onboard scoring, alternative A2, did show significant improvement over the current form of training. The level of improvement was not nearly as great as was obtained with the full features of OBS, which includes the synthetic target aircraft.

For six of the seven subjects, alternatives A4 (one OBS per each real encounter) and A6 (four OBS per each real encounter) are closely grouped for the highest expected utility value. Subject seven provided the only exception to this trend with alternatives A7 (six OBS per each real encounter) and A8 (all OBS encounters) also highly rated. In general, the expected utility decreases as the ratio of OBS encounters drops below one to one, or exceeds four to one. This narrows the selection of best training mix to between one and four OBS encounters per each real encounter.

TABLE 7-2

SUMMARY OF EXPECTED UTILITIES

ALTERNATIVE	EXPECTED UTILITY FOR SUBJECT A	1	2	3	4	5	6	AVERAGE UTILITY	NO. OF HIGHEST UTILITY	NO. OF LOWEST UTILITY
A1: CURRENT TRAINING (ALL REAL ENCOUNTERS)	.78	.81	.83	.87	.87	.72	.75	.80	0	5
A2: CURRENT TRAINING PLUS ONBOARD SCORING	.84	.85	.86	.93	.94	.79	.77	.85	0	0
A3: 1 OBS ENCOUNTER PER 2 REAL	.90	.89	.90	.95	.97	.87	.87	.91	0	0
A4: 1 OBS ENCOUNTER PER 1 REAL	.95	.92	.94	.97	.98	.93	.92	.94	5	0
A5: 2 OBS ENCOUNTERS PER 1 REAL	.94	.92	.93	.96	.98	.93	.93	.94	2	0
A6: 4 OBS ENCOUNTERS PER 1 REAL	.95	.92	.93	.95	.98	.94	.95	.95	5	0
A7: 6 OBS ENCOUNTERS PER 1 REAL	.90	.89	.86	.89	.95	.89	.92	.90	0	0
A8: ALL OBS TRAINING	.82	.82	.76	.74	.89	.85	.94	.83	0	2

7.3 Recommendations

The average expected utilities across all seven subjects for alternatives A4, A5 and A6 are 0.94, 0.94, and 0.95, respectively. The fidelity of the decision analysis is not fine enough to really distinguish between these three to select an obviously best alternative. Since all three alternatives involve a portion of OBS encounters, a recommendation to purchase OBS for operational training can be made with confidence. Only the specific balance of training remains to be determined.

A natural balance of OBS and real training may become obvious after OBS is available in operational aircraft. Based upon the model developed in Chapter 4, gun training currently amounts to slightly greater than nine percent of all F-15 flights (10,858 gun flights out of 119,712 total flights). Missile training dominates as the primary combat training mode, and tactical gunnery encounters are generally piggybacked during the missile training. Thus, tactical gun training is obtained without dedicated flights. Adding an occasional OBS flight would achieve a balance of training.

OBS has sufficient flexibility that it could also be used in spot situations to maximize training opportunities. If a pilot destroys a Dart tow target by scoring a direct hit, he could continue training with OBS rather than return to base. If two aircraft are flying tactical encounters and one returns to base due to a maintenance problem, the remaining aircraft could perform OBS encounters. Opportunistic uses of OBS could result in even greater benefits than defined in this study. Therefore, the exact ratio of OBS training should be optimized based upon real world experience.

If a training mix of two OBS encounters for each real encounter is assumed, a few interesting facts can be recalled from Table 5-1. Pilots would receive 398,204 training events compared to 175,259 currently; a 127 percent increase. Total flights would increase from 10,858 to 13,533; a 25 percent increase. More flights and training events are available for the same training budget. The advantages are obvious.

Future growth potential was not considered in the decision analysis, but is another advantage of OBS. Development of advanced display concepts like a helmet-mounted-display can be coupled with OBS to provide improved realism. Incorporation of air-to-air missile engagements in the software model could expand OBS into a total air combat simulation. This future potential is an added bonus.

7.4 Conclusions

The capability for OBS to realistically simulate air-to-air gunnery encounters was successfully demonstrated in the IFFC program. Direct cost savings of $6,616,650 resulted from using OBS in software development and test and evaluation. Other payoffs included improved safety of testing, pilot training, and involvement of engineers in the development testing.

This study applied decision analysis to examine the use of OBS in operational flight training in the air-to-air gunnery mode. Results strongly indicate that OBS would improve the quality of training which can be achieved within the existing budget. Thus, Air Force investment in OBS is highly recommended. The ratio of OBS and

real gun encounters is not critical and could vary from one to four OBS encounters for every real encounter. The value and utility of onboard simulation are apparent.

APPENDIX
TABLE A-1
IFFC FLIGHT SUMMARY

		ENCOUNTERS								
		AAG			BMG			AGG		
Flight	Duration	OBS	TAC	LIVE	OBS	TAC	LIVE	OBS	TAC	LIVE
1	1.6	-	-	-	-	-	-	-	-	-
2	1.7	-	-	-	-	-	-	-	-	-
3	1.3	5	-	-	-	-	-	-	-	-
4	1.5	22	-	-	2	-	-	-	-	-
5	1.7	-	-	-	-	-	-	-	-	-
6	1.4	7	-	-	5	-	-	-	-	-
7	1.6	13	6	-	-	6	-	-	-	-
8	1.1	15	6	-	-	-	-	-	-	-
9	1.6	23	-	-	-	-	-	-	-	-
10	1.5	19	-	-	-	-	-	-	-	-
11	1.5	-	-	-	29	-	-	-	-	-
12	1.7	7	-	-	14	-	-	-	-	-
13	1.6	18	-	-	-	4	-	-	-	-
14	0.7	-	-	-	-	8	-	-	-	-
15	1.7	-	-	-	9	7	-	-	-	-
16	1.5	-	6	-	-	-	-	-	-	-
17	1.6	-	-	-	5	6	5	-	-	-
18	1.3	-	20	-	-	-	-	-	-	-
19	1.5	-	-	-	2	5	2	-	-	-
20	1.7	-	9	2	-	-	-	-	-	-
21	1.7	-	-	-	-	11	5	-	-	-
22	1.7	2	-	-	-	6	3	2	3	-
23	1.6	-	-	-	-	-	-	-	-	-
24	1.7	-	-	-	-	-	-	-	-	-
25	0.4	-	-	-	-	-	-	-	-	-
26	1.2	-	-	-	-	-	-	27	-	-
27	1.4	-	-	-	-	-	-	-	-	-
28	1.7	7	-	-	2	-	-	39	-	-
29	1.6	2	-	-	5	1	-	40	-	-
30	0.9	-	-	-	-	9	2	-	-	-
31	1.3	-	-	-	-	-	-	51	-	-
32	1.6	-	-	-	-	10	12	10	-	-
33	1.6	60	-	-	-	-	-	22	-	-
34	1.8	-	11	-	16	4	-	-	-	-
35	0.8	19	-	-	16	5	-	-	-	-
36	1.3	-	-	-	-	-	-	-	-	-
37	1.7	-	-	-	-	-	-	-	-	-
38	1.5	36	17	-	-	-	-	-	-	-

TABLE A-1 CONTINUED

		ENCOUNTERS								
		AAG			BMG			AGG		
Flight	Duration	OBS	TAC	LIVE	OBS	TAC	LIVE	OBS	TAC	LIVE
39	1.0	11	2	-	-	-	-	-	-	-
40	0.9	2	-	6	-	-	-	-	-	-
41	1.5	5	11	-	10	-	-	-	-	-
42	1.7	-	16	-	-	13	-	-	-	-
43	1.8	-	-	-	-	-	-	-	-	-
44	1.6	37	13	-	-	-	-	-	-	-
45	1.7	19	-	-	-	13	-	-	-	-
46	1.5	19	-	-	9	12	-	-	-	-
47	1.1	-	-	-	-	-	-	-	-	-
48	1.5	-	-	-	-	10	12	-	-	-
49	1.6	5	7	-	-	10	-	-	6	-
50	1.4	-	12	-	-	7	-	-	-	-
51	1.5	-	27	-	-	-	-	-	-	-
52	1.3	-	10	2	-	-	-	-	-	-
53	1.5	4	-	-	-	16	-	-	-	-
54	1.4	27	19	-	-	-	-	-	-	-
55	1.7	-	-	-	-	14	-	-	-	-
56	1.5	28	25	-	-	-	-	-	-	-
57	1.5	-	20	-	-	6	-	-	-	-
58	1.3	-	-	-	-	15	3	-	-	-
59	1.4	6	21	-	2	2	-	-	-	-
60	1.0	15	16	-	-	-	-	-	-	-
61	1.5	3	18	-	-	3	-	-	-	-
62	1.4	-	9	-	-	7	-	-	-	-
63	1.0	2	7	-	-	-	-	-	-	-
64	1.0	-	1	1	-	-	-	-	-	-
65	1.6	15	-	-	11	11	-	-	3	-
66	1.5	9	13	-	-	14	-	-	-	-
67	1.7	-	-	-	-	13	9	-	-	-
68	1.4	28	15	-	-	-	-	-	-	-
69	1.4	-	-	-	-	24	11	-	-	-
70	1.4	18	-	-	-	17	2	-	-	-
71	1.3	43	25	-	-	-	-	-	-	-
72	1.5	14	-	-	-	8	-	-	-	-
73	1.6	55	-	-	-	3	-	-	-	-
74	1.6	27	-	-	-	12	-	-	-	-
75	1.3	-	-	-	-	-	-	-	-	-

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